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Sources and Emissions of Polycyclic Organic Matter (POM)

Radian Corp., Austin, TX

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This report is released to partially satisfy the requirements of Section 122 of the Clean Air Act, as amended in 1977. This report surveys Polycyclic Organic Matter (POM) sources and presents technical data used to support decision making on the need for listing POM under Section 108(a)(1), Section 112(b)(1)(A), or Section 111(b)(1)(A) as required by Section 122 of the Clean Air Act. Data are presented describing potential sources of POM emissions, control techniques used for POM emissions, and estimated POM emissions. A summary of estimated national POM emissions is provided. This summary includes estimates of natural POM emissions.

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SOURCES AND EMISSIONS
OF
POLYCYCLIC ORGANIC MATTER (POM)

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SOURCES AND EMISSIONS
OF
POLYCYCLIC ORGANIC MATTER (POM)

1.0 INTRODUCTION

The purpose of this report is to provide updated estimates of national polycyclic organic matter (POM) emissions for the man-made source categories listed in Table 1-1.

These estimates will allow EPA to identify major POM source categories based on current information and to assess the potential for achieving significant POM reductions within the established regulatory framework. Background information provided for each category will also allow EPA to make preliminary evaluations regarding the current regulatory status of the category, emission controls currently used, geographical distribution of sources, and future trends which may impact POM emission levels. Information provided for each source category, as available, is listed below:

- brief source category or process description including potential POM emission points,
- emission control methods (for pollutants other than POM) currently used, their effect on POM, and a brief discussion of NSPS, NESHAPs, or SIP air pollution regulations (if they are applicable),
- geographical locations of sources,
- available POM emission factors,
- national POM emission estimates for a baseline year, and

TABLE 1-1. POM SOURCE CATEGORIES EXAMINED

- Burning Coal Refuse and Other Open Burning
- Combustion of Solid, Liquid, and Gaseous Fuels for Heat and Power Generation
  - Utility coal, oil, and gas combustion
  - Industrial coal, oil, and gas combustion
  - Industrial wood combustion
  - Commercial/Institutional coal, oil, and gas combustion
  - Residential coal, oil, and gas combustion
  - Residential wood combustion
- Coke Production
- Iron and Steel Processes
- Asphalt Production
  - Hot Mix for Paving
  - Saturated Felt for Roofing
- Catalytic Cracking in Petroleum Production
- Combustion of Municipal, Industrial, and Commercial Wastes
- Carbon Black Production
- Wood Charcoal Production
- Vehicle Disposal
- Mobile Sources
  - Gasoline autos
  - Diesel autos
  - Diesel trucks
  - Tire wear

- o readily identifiable trends likely to influence POM emissions from the categories.

The report has been organized into four sections. Section 2.0 summarizes the national emission estimates for the source categories studied. A discussion of factors affecting data quality and the methodologies used to develop national estimates of total POM emissions is presented in Section 3.0. Natural sources of POM and man-made (anthropogenic) sources are described in detail in Sections 4.0 and 5.0, respectively.

The POM emission estimates presented are based on existing published information. No source tests or site visits were conducted. In most cases, the project scope and time constraints precluded a thorough examination of the source characteristics and emission test methods used to develop the published emission data. In some cases such information was not available. However, every effort has been made to use representative and well-documented emission factors available in the published literature. Questionable data and areas where additional information would be useful have been identified to facilitate further assessments in this area.

A fairly substantial amount of information has been published on specific types of POM emissions (most notably benzo(a)pyrene) from the source categories examined in this study. However, data were particularly scarce for forest fires and open burning, vehicle disposal, and burning coal refuse piles. Unfortunately, reporting of total POM emissions is not common. For some source categories emission factors were available only for a specific POM compound, for example benzo(a)pyrene (BaP), for benzene soluble organics (BSO), or for polynuclear aromatic hydrocarbons (PAH). Polynuclear aromatics are a subset of total POM. This distinction is discussed further in Section 3.1.1. While PAH emission factors were considered appropriate for developing total POM estimates, BaP and BSO were not used because there are no well-established correlations relating the amount of these compounds to the total POM emitted. (See Section 3.0). Thus, for a few source categories development of total POM emission estimates was not possible.

An important consideration involved in making relative comparisons between the total POM emission estimates developed here is that different published emission factors are very often inconsistent with respect to what POM compounds are included, even if the emission factor is defined as representative of "total POM". No attempt was made to resolve the differences in the bases of reported emission factors, but in each case the compounds included in the emission factor data used are identified (see Section 5.0).

There are three other areas of uncertainty or inaccuracy which can potentially influence the reliability of the emission estimates provided:

- sampling and analytical problems,
- accurate characterization of the emission control status of source categories, and,
- the accuracy of production or fuel consumption data used in calculating total POM emission estimates.

Pertinent factors in each of these areas are discussed in Section 3.0.

2.0 SUMMARY OF NATIONAL TOTAL POM EMISSION ESTIMATES

In this section national emission estimates for the source categories evaluated are summarized. The methodologies used to develop the estimates and factors which affect reliability of the estimates are discussed in Section 3.

Table 2-1 presents a summary of the 1980 national POM emission estimates for man-made source categories. These estimates generally reflect some degree of POM control resulting from application of particulate matter or other emission control technologies applied to facilities within the source category. Development of these estimates is discussed in detail in Section 5.0. Natural POM sources are discussed in Section 4.0. An effort has been made in Table 2-1 to provide a rough qualitative assessment of the relative reliability of the estimates. Relative reliability judgments were based primarily on the extent of data upon which emission factors were based, the estimated quality of the production or fuel consumption figures used to calculate national emissions, and the degree to which the emission control status of the source category could be reliably determined. The quality of the sampling and analytical techniques used to gather the published emission data was not considered in formulating the relative reliability estimates.

Table 2-1 also summarizes information on possible trends which may influence POM emissions from the source categories. The expected effect of the trends in increasing or decreasing emissions is noted where such a judgment was possible based on available information.

Table 2-1 shows that the most significant categories of POM emissions are (1) the combustion of wood in residential stoves and (2) mobile sources. The high level of POM emissions from residential wood combustion is due primarily

TABLE 2-1. SUMMARY OF 1980 NATIONAL POM ESTIMATES

Source Category	Estimated 1980 Annual POM Emissions Metric tons/yr (tons/yr)	Relative Reliability of Estimate[a]	Trends Influencing POM Emissions	Effect of Trends on POM Emissions
BURNING COAL REFUSE AND OTHER OPEN BURNING				
o Burning coal refuse piles, outcrops, mines	12.2 (13.4)	Poor	Required preventative disposal; extinguishing existing fires	Decrease
o Agricultural Open Burning	DNA[b]	--	(Possibly) more diligent enforcement of open burning regulation	No change or slight decrease
o Prescribed burning (fire management)	300 (330)	Very Poor	Long-term: improved fire control techniques to reduce POM	No change or slight decrease
COMBUSTION OF SOLID, LIQUID AND GASEOUS FUELS FOR HEAT AND POWER GENERATION				
Utility Combustion				
o Coal	9.1 (10.0)	Good	NSPS for new units; requirement of PM[c] control for fuel switching (to coal); projections of fossil fuel-fired utility growth are variable, but new capacity growth has slowed in recent years.	No change or slight decrease because of stringent emission control for new units.
o Oil	2.2 (2.4)	Fair		
o Gas	2.1 (2.3)	Good		
Industrial Combustion				
o Coal	1.5 (1.7)	Fair	Pending NSPS requiring PM control for new boilers; increased use of coal; industrial growth. Projected growth in wood consumption; pending NSPS requiring PM control	Slight increase possible if coal-use in industrial boilers increases significantly.
o Oil	0.48 (0.53)	Fair		
o Gas	1.1 (1.2)	Fair		
o Wood	59.6 (65.6)	Fair		
Commercial/Institutional (C/I) Combustion				
o Coal	0.17 (0.19)	Poor	Growth in urban areas requiring C/I boilers; some subject to pending NSPS for PM control, others only to SIP or local regulations	d
o Oil	0.30 (0.33)	Poor		
o Gas	0.84 (0.92)	Poor		

(Continued)

TABLE 2-1. SUMMARY OF 1980 NATIONAL POM ESTIMATES (Continued)

Source Category	Estimated 1980 Annual POM Emissions Metric tons/yr (tons/yr)	Relative Reliability of Estimate[a]	Trends Influencing POM Emissions	Effect of Trends on POM Emissions
Residential Combustion				
o Coal	172 (189)	Fair	Decreasing use of coal but predicted increase in use of wood; widespread use of emission controls not likely in the near future	Possibly significant increase due to increased wood consumption.
o Oil	3.8 (4.2)	Fair		
o Gas	14.7 (16.2)	Fair		
o Wood Stoves	7022 (7724)	Poor to fair[e]		
o Wood Fireplaces	502 (552)	Poor to fair		
COKE PRODUCTION	363 (399)	Poor to fair[f]	Pending coke oven NESHAPS continued control through SIPs; moderate growth (1 to 3%) tied to steel industry	Possible decrease because of NESHAPs (new and existing sources)
IRON AND STEEL PROCESSES				
o Sintering	DNA	--	Low to moderate growth in production (1 to 3%); new and some existing ferroalloy facilities subject to NSPS	No change or possible decrease
o Ferroalloy production				
- covered furnaces	DNA	Fair		
- open furnaces				
ASPHALT PRODUCTION				
o Hot mix for paving	0.29 (0.32)	Good	NSPS for some existing and new hot mix plants; no significant changes in production levels; housing industry growth; NSPS controls for roofing product plants	Difficult to assess because of lack of data on effect of particulate controls on POM emissions
o Saturated felt for roofing	0.03 (0.03)	Good		
CATALYTIC CRACKING IN PETROLEUM PRODUCTION	0.31 (0.34)	Good	2 to 3% drop in amount of oil subject to cracking; more efficient cracking; NSPS for new and some existing fluid catalytic cracking operations	Decrease

(Continued)

TABLE 2-1. SUMMARY OF 1980 NATIONAL POM ESTIMATES (Continued)

Source Category	Estimated 1980 Annual POM Emissions Metric tons/yr (tons/yr)	Relative Reliability of Estimate[a]	Trends Influencing POM Emissions	Effect of Trends on POM Emissions
COMBUSTION OF MUNICIPAL, INDUSTRIAL, AND COMMERICAL WASTES				
o Municipal solid waste incineration	0.14 (0.15)	Fair	Municipal-trend toward large, more efficient incinerators and boilers; NSPS requiring PM control for new units, relatively low growth	Municipal-slight decrease or no change
o Commercial and industrial incineration	440 (484)	Poor[g]		
o Municipal solid waste-fired boilers	DNA	--	Industrial-decreased incineration due to PM emission control requirements; possible unregulated combustion of hazardous wastes in boilers; increase in incineration with heat recovery (wood products industries) and for resource recovery; no NSPS for new sources	Industrial-difficult to predict
o Refuse-derived fuel-fired boilers	DNA	--		
CARBON BLACK PRODUCTION	2.1 (2.3)	Fair	Annual growth rate 2 to 3%, new plants subject to SIPs; no NSPS	Slight increase possible
WOOD CHARCOAL PRODUCTION	1.3 (1.4)	Fair	General trend toward larger plants that are more amenable to emission control; no indication of significant growth	No change or slight decrease
VEHICLE DISPOSAL	DNA	--	Trend toward more efficient incineration of shredded auto body steel in rotary incinerators; continued open burning prohibitions	Decrease

(Continued)

TABLE 2-1. SUMMARY OF 1980 NATIONAL POM ESTIMATES (Continued)

Source Category	Estimated 1980 Annual POM Emissions Metric tons/yr (tons/yr)	Relative Reliability of Estimate[a]	Trends Influencing POM Emissions	Effect of Trends on POM Emissions
MOBILE SOURCES				
o Gasoline-fueled autos and trucks, diesel autos and trucks, buses, motorcycles, railroads, aircraft, etc.	6400 (7040)[h]	Poor	Gasoline-consumption in autos expected to decrease because of increased diesel use, conservation, high-mileage models; continued use of emission controls	Gasoline-decrease
			Diesel-increased diesel use in autos, no emission controls generally used	Diesel-increase
o Rubber tire wear	DNA	--	No significant changes expected	No change
TOTAL MAN MADE	15311 (16842)[i]			

[a] Scale is Very Poor, Poor, Fair, Good. Basis for assessments is discussed in text.

[b] DNA: POM emission factor data required to develop national estimate not available.

[c] PM: particulate matter. Control of PM, especially fine particulate matter will result in control of associated POM. Typical controls (for new sources) are ESPs, fabric filters, (efficient for fine PM), and wet scrubbers (high pressure drop types efficient for PM and also control vapor-phase POM).

[d] Trends will depend on fuel choice-increased use of coal may result in increased POM if efficient PM controls not required.

[e] Wide range of emission factors in literature; uncertainty in wood combustion data.

[f] Based only on door leaks and quenching tower emission, the two process operations for which POM data were available.

[g] Inadequate emission factor and waste combustion data.

[h] Estimate based on actual data and derived emission factors for specific PAH compounds. Literature suggests multiplying this value by 3 to estimate total PAH emissions (i.e., 6400 x 3 = 19,000 metric tons). Based on 1979 fuel consumption data.

[i] Does not include 824 metric tons/year (906 tons/year) POM emission estimates for wildfires.

to the inefficient combustion conditions in wood stoves. Also, the level of wood consumption in residential stoves has increased significantly in the last few years (see Section 5.3.4). However, it should be noted that a wide range of POM emission factors for this category was found in the literature. Reported emissions factors varied between 0.05 and 0.37 gm POM per kg of wood burned. Thus, national POM estimates for this category could vary from 1300 to 9600 metric tons/yr. (A 0.27 gm/kg factor was used to calculate the estimate reported in Table 2-1. This value is an average of six well-documented emissions tests of representative wood stoves.) Emissions from this category are projected to increase due to increased wood consumption and the lack of emission controls on residential stoves.

The value for the mobile sources category represents total mobile source emissions of 27 specific PAH compounds. (As discussed in Section 1, when no total POM emission data were located, estimates of PAH emissions were used.) The authors of the report from which the estimate in Table 2-1 was obtained suggest that this value should be multiplied by three to estimate "total PAH" emissions for this category, resulting in an annual emission estimate of 19,000 metric tons. However, the authors also note that their emission factors, which are based on very limited available emission data for certain PAH compounds "extrapolated" to estimate total PAH emissions from different types of mobile sources, are uncertain by at least a factor of 2. The more conservative estimate has been included in Table 2-1 since little information was provided to support tripling this value to obtain total PAH.

Other source categories for which the estimated POM emissions are relatively significant include prescribed burning for forest fire management, industrial wood combustion, residential coal combustion, wood fireplaces, coke production, ferroalloy production, and commerical and industrial incineration. Of these categories, emissions from industrial wood combustion and industrial incineration may potentially increase in the next few years.

Development of total POM estimates was not possible for agricultural open burning, iron and steel sintering, waste-fired boilers, or vehicle disposal. Generally, the only POM-related emission factor data available for these categories were in terms of benzo(a)pyrene (BaP).

3.0 RELIABILITY OF EMISSION ESTIMATES

The purposes of this section are to briefly explain some of the problems associated with developing total POM emission estimates from available data (Section 3.1) and to give the reader a general picture of the quality of total POM data contained in available publications (Section 3.2).

In categories for which adequate data were available, national total POM estimates were generally developed by multiplying a POM emission factor (in terms of POM per unit of production or consumption) by national production or consumption values for the baseline year of 1980.

Emission factors used in developing national POM estimates were obtained from published literature. No source tests were conducted. The general sampling and analytical techniques used in the original tests were noted where such information was readily available. In addition, the specific POM compounds included in the reported emission factors were listed (when that information was available). As previously stated, a thorough examination of source characteristics and emission test methods used in collecting the reported emission data was not possible within the scope and time frame of this study.

National production or fuel consumption data were obtained from published sources for the baseline year of 1980. For categories in which no 1980 production or consumption data were readily available, estimates were developed by extrapolating the most recent data located.

The specific methodology used to estimate emissions for each man-made source category is documented in the text (Section 5.0). Additional information on the development of national estimates for utility, industrial, commercial, and residential combustion sources is provided in Appendix A.

3.1 DEVELOPING TOTAL POM ESTIMATES

3.1.1 Emission Factors for POM

The emission factors used in Section 5.0 to develop national total POM estimates are subject to considerable uncertainty. This section discusses some of the problems associated with using available published emission factor data for total POM.

Table 3-1 lists some of the POM compounds identified in air emission samples. The list was compiled from three references (1,2,3) and thus does not represent an extensive search of the literature. However, all the major POM compounds are included (although all their isomers may not be listed). Reported POM emission factors for the various source categories vary with respect to what compounds are actually included in the emission data. This is an important consideration when comparing the POM emission estimates developed for various source categories.

Many of the past emission data gathering efforts have focused on one particular POM compound: benzo(a)pyrene (BaP). This compound has been targeted primarily because it is a known animal carcinogen and because it is relatively easy to separate and identify. However, BaP data cannot reliably be used to develop total POM emission estimates because (1) there is no well-established data base on BaP/POM ratios and (2) BaP/POM ratios appear to be a function of source type and, in some cases, operating conditions of the source. Table 3-2 shows POM ratios calculated from the most recent comprehensive report on POM emission sources (4). The ratios shown in Table 3-2 are based on the intermediate weighted average emission factors given in Reference 4. However, all the emission factors in the referenced report are based on fairly limited data and are of questionable value due to significant variations in sampling and analytical techniques. Because of these concerns about the reliability of any BaP/POM ratios they were not used to develop total POM estimates.

TABLE 3-1. COMPARISON OF POM AND PAH COMPOUNDS[a]

POM Compound[b]	Included in PAH?[c]
Anthracene	Yes
Benz(a)anthracene	Y
7,12-dimethylbenzanthracene	Y
Dibenzanthracenes	Y
Methylanthracene	Y
Ethylanthracene	Y
Methyl-benzo[a]anthracene	Y
Aceanthrylene	Y
Benz(j)aceanthrylene	Y
3-Methylcholanthrene	Y
Acridine	N
Anthanthrene	Y
Methylanthanthrene	Y
Benzidene	N
Benziquinoline	N
Biphenyl	Y
Methylbiphenyl	Y
Polychlorinated biphenyls	N
Chrysene	Y
Methylchrysene	Y
Dimethylchrysene	Y
Benzo(b)chrysene	Y
Methylbenzo(b)chrysene	Y
Coronene	Y
Fluorene	Y
Methylfluorenes	Y
Fluorene carbonitrile	N
Benzofluorenes	Y
Dibenzofluorenes	Y

(Continued)

TABLE 3-1. COMPARISON OF POM AND PAH COMPOUNDS[a] (Continued)

POM Compound[b]	Included in PAH?[c]
Fluoranthene	Y
Methylfluoranthene	Y
Trimethylfluoranthene	Y
Benzo(g,h,i)fluoranthene	Y
Methylbenzo(g,h,i)fluoranthene	Y
Benzfluoranthenes	Y
O-phenylene-fluoranthene	Y
Methyl-o-phenylene-fluoranthene	Y
Napthene	Y
Naptho(2,3-a)pyrene	Y
β,β'-Binapthyl	N
Perylene	Y
Benzo(g,h,i)perylene	Y
Methylbenzo(g,h,i)perylene	Y
Phenanthrene	Y
Methylphenanthrene	Y
Ethylphenanthrene	Y
Dimethylphenanthrene	Y
Benzophenanthrenes	Y
Picene	Y
Pyrene	Y
Benzo(a)pyrene	Y
Benzo(e)pyrene	Y
Dibenzopyrenes	Y
Indeno(1,2,3-c,d)pyrene	Y
Methylpyrene	Y
Trimethylpyrene	Y
Methylbenzopyrenes	Y
Dimethylbenzopyrenes	Y
Methyl Indeno(1,2,3-c,d)pyrene	Y
Benzo(c)tetraphene	Y
Methylbenzo(c)tetraphene	Y
Triphenylene	Y
Methyltriphenylene	Y

(Continued)

TABLE 3-1. COMPARISON OF POM AND PAH COMPOUNDS[a] (Continued)

POM Compound[b]	Included in PAH?[c]
Others	N
Carbazole	N
Benzo(a)carbazole	N
Dibenzocarbazoles	
Polychloriated dibenzo-p-dioxins	N
Polychlorinated dibenzofurans	N
Imino arenes e.g., aromatic HC with ring N with a H	N
Carbonyl arenes e.g., aromatic HC with one ring carbonyl group	N
Dicarbonyl arenes (quinones) e.g., two ring carbonyl groups	N
Hydroxy carbonyl arenes e.g., ring carbonyl aromatic HC with hydroxy groups and possibly alkoxy or acyloxy group	N
Oxa-arenes e.g., aromatic HC with ring O atom	N
Thia arenes e.g., aromatic HC with ring S atom	N

[a] Based on limited sources of information.

[b] Refs 1, 2, and 3. Not all synonyms shown.

[c] PAH = polycyclic aromatic hydrocarbons as defined in Reference 1.

TABLE 3-2. BaP/POM AND BSO/POM RATIOS CALCULATED FROM READILY AVAILABLE DATA (4)

Source	Emission Control	BaP/POM	BSO/POM
PC[a] Boiler-Utility Vertical-fired	None	0.08	
(Coal) Vertical-fired	MC[d]/ESP	0.08	
Front wall-fired	ESP	0.05	
Tangentially-fired	MC/ESP	0.16	
Opposed firing	MC	DNR[e]	
Cyclone-fired utility boiler	ESP	0.04	
Spreader stoker utility boiler	MC	0.11	
Utility boiler-total population[b]	"Controlled"	0.08	
Industrial coal-fired boilers-total[b]	None	0.02	
Residential coal-fired boilers-total[b]	None	0.05	
Residential coal stoves[b]	None	DNR	
Residential fireplaces[b]	None	0.04	
Industrial oil-fired boilers-total[b]	None	0.05	
Comm/Inst. oil-fired boilers-total[b]	None	0.05	
Residential oil-fired heating-total[b]	None	0.02	
Indusrial gas-fired boilers	None	0.06	
Residential gas-fired heating	None	0.03	
Catalytic cracking-total[b]	None	0.01	180
Catalytic cracking-total[b]	CO Boiler	0.04	3.8
Coke Production			
Wet charging	?	DNR	DNR
Pushing	?	DNR	DNR
Quenching	?	3.33×10^{-6}	1.0
Door leaks	?	0.33	58
Battery stacks	?	DNR	DNR
Asphalt saturators-general	"Controlled"	0.25	
Air blowing-total[b]	"Controlled"	0.02	
Hot mix	Cyclone	0.07	
Hot mix	Cyclone & spray tower	0.01	
Iron and steel sintering	None	DNR	
Carbon black	None	DNR	
Municipal incinerators-total[b]	"Controlled"	0.01	
Commercial incinerators-total[b]	None	0.04	

(Continued)

TABLE 3-2. BaP/POM AND BSO/POM RATIOS CALCULATED FROM READILY AVAILABLE DATA (4) (Continued)

Source	Emission Control	BaP/POM	BSO/POM
Open burning			
- Municipal refuse	None	0.12	
- Auto bodies/components	None	0.14	
- Grass, leaves, branches	None	0.11	
Bagasse boilers	Cyclone	0.01	
Forest fires heading	None	3.8×10^{-3}	
backing	None	0.02	
Gasoline autos-total[c]	c	DNR	
Diesel autos-total[c]	None	DNR	
Diesel trucks	None	1.2×10^{-3}	

[a] PC: pulverized coal.

[b] Weighted average of total population of sources in category.

[c] Weighted average based on 1976 auto population.

[d] MC: mechanical collector.

[e] DNR: Data not reported.

Another "indicator" of POM emissions, often used in reporting coke oven emissions, is benzene soluble organics (BSO). Although most POM compounds (including BaP) are soluble in benzene, BSO is not necessarily equivalent to POM because it includes compounds other than POM (6). It has been established that BaP is generally about 1 percent of BSO in coke oven emissions (7). However, since this correlation applies only to coke ovens and since BSO includes compounds that are not POM, the correlation was not considered useful for developing total POM estimates.

More recently, techniques have evolved for sampling and analysis of polynuclear aromatic hydrocarbons (PAH). These compounds are a subset of total POM as indicated by Table 3-1. Measurements of PAH do not include such POM groups as aza arenes, imino arenes, carbonyl and dicarbonyl arenes, hydroxy carbonyl arenes, oxa-and thia-arenes, and polychlorinated polycyclic compounds. However, PAH does include most of the major POM compounds and, as such, PAH emission factors were considered to be appropriate for use in developing total POM estimates where no other data were available.

Some total POM emission factors have been reported in the literature, although most of these data were collected in two or three studies in the late 60's and early 70's. These initial studies have been cited repeatedly in more recent reports, but not much new total POM emission data have been collected.

The general emission test method used in collecting the reported data, the compounds included in the measurement(s), and the key characteristics of the source(s) tested have been reported here when such information was readily available in the literature sources used in this study.

3.1.2 National Emission Estimates

The most uncertain aspect of developing national emission estimates for a source category is the assumption that an emission factor based on limited test data for a narrow range of sources can be considered representative of the entire source category. In reality, POM emissions from specific sources will vary with:

- raw materials used,
- process design and operating conditions, and
- emission control technology applied.

Most of the emission factor data used was reported to have been obtained from "representative sources" with respect to raw materials and process design and operating conditions. In some cases, emission factors for a weighted average source population had been developed in the literature. Variations in raw material and process conditions tend to be averaged out over the source category population and thus should not interfere greatly with the development of useful national emission estimates.

The impact of emission control technology application is more difficult to assess. Emission factors reported in the literature vary with respect to whether they were measured before or after the emission control device. Additionally, there is a significant lack of data regarding the effect of technologies designed to control other pollutants (particulate, NO_x, SO_2, CO, or hydrocarbons) on POM emissions. Finally, "controlled" emission factors in the literature may not be representative of the emission control technologies currently used in the source category.

During the course of developing national emission estimates, applicable Federal air pollution regulations (NSPS, NESHAPs) were briefly reviewed to determine the emission controls required for sources subject to such regulations. Also, readily available published information on the current use of emission controls in the source category was assembled. Engineering judgments were made in some cases to use emission factors representative of the application of a particular technology to the entire source category. Despite these efforts, however, the national impact of current non-POM emission control technology requirements on POM emissions is difficult to assess (even qualitatively) and is likely to be a major factor in the usefulness of the national POM estimates developed in this study.

National production or fuel consumption estimates inherently contain some inaccuracies associated with the collection and documentation of such data. For the following source categories the data used to develop national estimates were considered particularly susceptible to inaccuracies:

- tonnages of material burned in forest fires and other open burning,
- tonnages in burning coal refuse piles, outcrops, and abandoned mines,
- residential wood consumption, and
- the amounts of refuse combusted in municipal, industrial, and commercial incinerators.

3.2 QUALITY OF REPORTED EMISSIONS DATA

Much of the POM emitted is associated with small particles entrained in the exhaust gases from the source (i.e. plant or process equipment). Therefore, high small particle collection efficiency is an important consideration in the accuracy of the sampling apparatus used in measuring POM emissions. EPA Method 5, which has been adopted as a standard method for measuring particulate matter emissions, is the method most commonly employed to measure POM from stationary emission sources.

Some POM compounds from certain sources are emitted as vapor. The vapor-phase POM emissions are not totally captured by the typical Method 5 particulate sampling apparatus used to measure POM. Depending on the temperature of the source stream and the sampling apparatus temperature, undetected emissions of POM may be significant (8).

Another problem with typical POM measurements is the potential for loss of POM already trapped on the sampling train filter. Such losses are reported to increase with increasing gas velocity and increasing gas temperature. POM losses can also occur through chemical rearrangement of the collected substances on the filter surface. One source has reported that POM emission measurements based on conventional Method 5 particulate sampling techniques are low by a factor of 2 to 200 (8). Modified Method 5 techniques using impingers and solvent-filled bubble trains have been shown to substantially reduce POM losses. Advanced techniques using sorbent resins to capture vapor phase POM can result in much more accurate results, but these techniques do not appear to generally have been used in collecting the available data reported in much of the published literature.

A variety of analytical methods have been and are being used to analyze the collected samples for POM. Apparently, agreement between POM concentrations obtained with different analytical techniques can be "expected to be no more than an order of magnitude (9)."

In summary, the uncertainty and variability associated with POM sampling and analysis techniques cast substantial doubt upon the accuracy of POM emission factors reported in the literature. Virtually all of the literature sources reviewed have included such a caveat in cautioning readers about usefulness of the data reported.

3.3 REFERENCES

1. Merrill, Ray (IERL-RTP), Process Measurements Branch. Telephone conversation with Mary Kelly (Radian Corp.). March 16. 1983.

2. National Academy of Sciences. Particulate Polycyclic Organic Matter. Washington, DC, pp. 4-12, 1972.

3. White, J. B., and R. R. Vanderslice (Research Triangle Institute, Inc.). POM Source and Ambient Concentration Data: Review and Analysis. EPA-600/7-80-044, U.S. Environmental Protection Agency, Research Triangle Park, NC, p. 52, March 1980.

4. Haro, J. T. (Energy and Environmental Analysis, Inc.) Preliminary Assessment of the Sources, Control and Population Exposure to Airborne Polycyclic Organic Matter (POM) as Indicated by BaP. Final Report, Prepared for U.S. Environmental Protection Agency, Research Triangle Par, NC, pp. 22-35, November 10, 1978.

5. U.S. Environmental Protection Agency. Scientific and Technical Assessment Report on Particulate Polycyclic Organic Matter. EPA-600/75-001, Washington, DC, March 1975.

6. Emission Standards and Engineering Division. Coke Oven Emissions from By-Product Coke Production - Background Information for Proposed Standards. Draft Report, U.S. Environmental Protection Agency, Research Triangle Park, NC, pp. 3-17, March 1981.

7. Reference 6, p. 3-19.

8. Reference 3, Chapters 2 and 4.

9. Reference 3, p. 27.

4.0 NATURAL SOURCES OF POM

Natural sources of POM emissions are basically natural combustion sources such as forest fires and volcanoes. Data on total POM emissions from natural sources are scarce. The only readily available emission factors located were from laboratory tests of burning pine needles. These emission factors and corresponding national estimates are discussed below.

Table 4-1 shows POM emission factors reported for the laboratory forest fires (1). As indicated, the emission factors vary by up to three orders of magnitude depending on the type of fire. Other variables that significantly impact emissions from forest fires are:

- the type of vegetation burned,
- burning conditions, and
- weather conditions.

In 1980, the U.S. Forest Service estimates that 1.8×10^{10} m^2 (4.43 million acres) were burned in wildfires (2). This figure includes all types of wildfires, from grasslands to forests. At an average of 2.3 kg/m^2 (10.4 tons/acre burned), this amounts to approximately 41.2 million metric tons/yr (45.3 million tons/yr) of vegetation burned in 1980 (2).

The average intermediate POM emission factor for all types of fires included in the lab study results is 20 mg/kg burned. Multiplying this emission factor by the total estimate tonnage burned in 1980 yields a rough estimate of national POM emissions from wildfires of:

TABLE 4-1. EMISSION FACTORS FOR LABORATORY FOREST FIRES (1)[a]

Type of Forest Fire	POM Emission Factor[b] (mg/kg burned) Minimum	Intermediate	Maximum
Heading (flaming)	3.46	5.3	8.39
Heading (smoldering)	21.8	26	31.5
Heading (overall)	7.63	14	22.8
Backing (overall)	10.2	36	172

[a] Tests involved burning pine needles in a controlled environment burning room. A modified "hi-vol" sampler was used to collect particulate samples. Samples were extracted with methylene chloride, separated by liquid chromotography and analyzed by GC/MS.

[b] Compounds measured: anthracene, phenanthrene, methyl anthracene, fluoranthene, pyrene, methyl pyrene, benzo(c)phenanthrene, chrysene, benzo(a)anthracene, methyl crysene, benzofluoranthenes, benzo(a)pyrene, benzo(e)pyrene, perylene, methylbenzopyrenes, Indeno (1,2,3-c,d)pyrene, and benzo(g,h,i)perylene.

$$\left(41.2\ \frac{\text{million metric tons}}{\text{yr}}\right)\left(20\ \frac{\text{gm}}{\text{metric ton}}\right)\left(\frac{\text{metric ton}}{10^6\ \text{gm}}\right)$$

= 824 metric tons/yr (906 tons/yr)

It should be noted that this estimate is very rough for two reasons:

- Very limited emission factor data were available, and those data were from laboratory fires burning only one type of vegetation.
- Estimates of acreage and tonnage burned in wildfires are uncertain and widely varied.

4.1 REFERENCES

1. Energy and Environmental Analysis, Inc. Preliminary Assessment of the Sources, Control and Population Exposure to Airborne Polycyclic Organic Matter (POM) as Indicated by Benzo (A) Pyrene (BaP). Final Report, Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, p. 29, November 10, 1978.

2. Yamate, George (IIT Research Institute). Emissions Inventory from Forest Wildfires, Forest Managed Burns, and Agricultural Burns, EPA-450/3-74-062, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, p. 7, November 1974.

5.0 MAN-MADE SOURCES AND EMISSION ESTIMATES

5.1 INTRODUCTION

This section presents the development of national total POM emission estimates for the source categories shown in Table 5-1. The following sections discuss each of the following items for each source category:

- a brief source category or process description with identification of POM emission points and the key factors influencing emissions,
- emission control methods (for compounds other than POM) currently used in the source category, their effect on POM emissions and a brief discussion of applicable NSPS, NESHAPs, and SIP air pollution regulations,
- geographical locations of sources,
- available emission factor data,
- national emission estimates for a baseline year, and
- readily identifiable trends in technology, source category growth, or emission regulations that are likely to influence POM emissions.

The baseline year for emission estimates was chosen as 1980. In addition to providing relatively recent information, this year required a minimum of extrapolation of production and fuel consumption data used to calculate national emissions.

A summary of national emission estimates for the various source categories is contained in Section 2.0.

TABLE 5-1. POM SOURCE CATEGORIES EXAMINED

Section No.		Category
5.2	o	Burning Coal Refuse and Other Open Burning
5.3	o	Combustion of Solid, Liquid, and Gaseous Fuels for Heat and Power Generation - Utility coal, oil, and gas combustion - Industrial coal, oil, and gas combustion - Industrial wood combustion - Commercial/Institutional coal, oil, and gas combustion - Residential coal, oil, and gas combustion - Residential wood combustion
5.4	o	Coke Production
5.5	o	Iron and Steel Processes
5.6	o	Asphalt Production - Hot Mix for Paving - Saturated Felt for Roofing
5.7	o	Catalytic Cracking in Petroleum Production
5.8	o	Combustion of Municipal, Industrial, and Commercial Wastes
5.9	o	Carbon Black Production
5.10	o	Wood Charcoal Production
5.11	o	Vehicle Disposal
5.12	o	Mobile Sources - Gasoline autos - Diesel autos - Diesel trucks - Tire wear

5.2 BURNING COAL REFUSE AND OTHER OPEN BURNING

The section discusses three sources of POM emissions:

- burning coal refuse piles, outcrops, and mines
- agricultural open burning, and
- prescribed open burning (forest fires).

Unprescribed burning of leaves, grass, and other materials was not considered because of (1) the difficulty of obtaining meaningful data on emission factors and tonnage burned and (2) the widespread prohibition of unprescribed open burning (1).

5.2.1 Source Category Description

5.2.1.1 Process Description

Coal Refuse Piles, Outcrops, and Mines -- Waste material separated from coal is often piled into banks near coal mines or coal preparation plants. The waste material is referred to as coal refuse, gob, culm, or reject material. Indiscriminant dumping and poor maintenance of refuse piles are two practices that can result in spontaneous combustion of refuse piles (2). Spontaneous combustion of coal can also result in fires in abandoned mines, outcrops, and impoundments. Emissions of POM from these sources are influenced by oxygen concentration, type of coal and refuse, relative humidity of the ambient air, and moisture content and temperature of the burning material (3).

Agricultural Open Burning -- Open burning is performed in some rural areas as a means of controlling agricultural wastes. The burning is carried out in open drums or baskets, large-scale open dumps, or pits (4). The relatively low burning temperatures and inefficient combustion typical of agricultural open burning make it a potential source of POM. Emissions will vary widely with the type of waste burned and burning conditions.

Prescribed Open Burning -- Prescribed open burning of forests is practiced to reduce the chances of wildfires. Prescribed burning is usually well-controlled and occurs at a lower intensity than wildfires. However, combustion tends to be incomplete due to the high moisture content and varying composition of the materials burned (5). Thus, prescribed burning is a source of POM emissions. Emissions of POM will vary widely with the material being burned, burning conditions, and weather conditions.

5.2.1.2 Emission Controls/Regulations

Coal Refuse Piles, Outcrops, and Mines -- Various techniques exist to control particulate and gaseous emissions from burning coal refuse piles, outcrops, and abandoned mines. These techniques are based on cutting off the oxygen source to extinguish the fire and on preventing the fire from spreading. The control techniques for coal refuse piles include quenching the pile with water and blanketing it with an incombustible material. Control techniques for outcrops and abandoned mines include the use of fire barriers, surface sealing, and flushing void spaces with water or an incombustible material (6).

No data were available on the use of these control techniques for existing fires. However, in 1975 the U.S. Department of the Interior promulgated regulations that require coal companies to dispose of coal refuse in a manner that prevents or minimizes the chances for spontaneous combustion (6).

Agricultural Open Burning -- Most states have regulations that prohibit open burning. However, agricultural burning is not specifically restricted in any of the states (4). Some states do require the farmer to obtain a permit and also give local air pollution control authorities discretion over when burns can occur (4).

Prescribed Open Burning -- POM emissions from prescribed open burning can be reduced somewhat by attempting to maintain well-controlled and efficient burning. No data were available, however, to characterize POM emissions as a function of burning conditions.

5.2.1.3 Source Locations

Coal Refuse Piles, Outcrops, and Mines -- Locations of these sources are, of course, linked to mining locations. Kentucky, West Virginia, and Pennsylvania accounted for about 63 percent of burning coal refuse and impoundments in 1972. Montana, Wyoming, Colorado, and New Mexico accounted for about 66 percent of burning abandoned mines and outcrops. Other states in which these sources are located include Alabama, Ohio, and Virginia (2).

Agricultural Open Burning -- Limited data indicate that agricultural burning (in terms of total acres burned) is prevalent in California, Florida, Georgia, Hawaii, Kansas, Louisiana, Mississippi, North Carolina, Oregon, and Washington all of which have significant levels of agricultural activity (4).

Prescribed Burning -- Data on the acreage of prescribed burns by state were not located. However, based on state-specific particulate estimates from prescribed burning, the states where prescribed burning is used to a relatively larger extent (than in other states) are Florida, Georgia, Idaho, Montana, North Carolina, South Carolina, Tennessee, Texas, Washington, and West Virginia (7).

5.2.2 Emission Factors

Coal Refuse Piles, Outcrops, and Mines -- Preliminary sampling of emissions from a burning coal refuse pile was conducted by Monsanto Research Corp. (2). Particulate matter collected from a representative coal refuse pile using "hi-vol" sampling equipment was analyzed for POM. A total POM emission rate of 0.019 mg/m^3-hour of burning coal refuse was reported. Based on an average density of 1.5 metric tons/m^3 for refuse piles, this translates into 0.013 mg/hour-metric ton of refuse burned. The POM compounds measured are shown in Table 5-2.

Agricultural Open Burning -- No POM emission factor data were available for agricultural open burning.

Prescribed Burning - No POM emission data were available specifically for prescribed burning. Therefore, the emission factors presented in Section 4.0 for laboratory forest fires were used to develop the estimates.

5.2.3 National Emissions Estimates

Coal Refuse Piles, Outcrops, and Mines -- Estimates of the amounts of burning coal refuse in piles, outcrops, and mines are difficult to develop. Reference 2 reports that in 1968 there were about 250 × 10^6 metric tons (275 million tons) of coal refuse in piles, but no estimates were given for impoundments, outcrops, or abandoned mines. A representative coal refuse pile was defined as having the following characteristics (2):

- o volume: $1.7 \times 10^6 m^3$
- o dry density: 1.5 metric tons/m^3
- o percent of pile burning: 21

The total number of active piles in 1972 was estimated at 206 (2). Based on "typical pile" characteristics and the number of piles the estimated amount of burning coal refuse in piles is:

$$(206 \text{ piles})(1.7 \times 10^6 m^3/\text{pile})(1.5 \text{ metric tons}/m^3)(.21)$$
$$= 110 \text{ million metric tons (121 million tons)}$$

This is less than half the total tonnage estimate given in Reference 2 which was based on a Bureau of Mines estimate of "refuse material contained in coal piles." Because not all the material is likely to be burning, the 110 million metric ton figure calculated above is more suitable for use in calculating

TABLE 5-2. POM COMPOUNDS IDENTIFIED IN PARTICULATE EMISSIONS FROM BURNING COAL REFUSE PILES (2)

Dibenzothiophene
Anthracene/phenanthrene
Methylanthracenes/phenanthrenes
9-Methylanthracene
Fluoranthene
Pyrene
Benzo(c)phenanthrene
Chrysene/benz(a)anthracene
Dimethylbenzoanthracenes
Benzo(k or b)fluoranthene
Benzo(a)pyrene/Benzo(e)pyrene/pyrene
3-Methylcholanthrene
Dibenz(a,h or a,c)anthracene
Indeno(1,2,3-c,d)pyrene
9H-Dibenzo(c,g)carbazole
Dibenzo(a,h or a,i)pyrene

national emission estimates from coal refuse piles. Due to a lack of more recent data, the number of piles was assumed to be the same in 1980 as for 1972.

Thus, national POM emissions from coal refuse piles were estimated to be:

$$\left(\frac{0.013\ \text{mg}}{\text{metric ton/h}}\right)\left(110\ \text{million metric tons}\right)\left(\frac{8760\ \text{hr}}{\text{yr}}\right)\left(\frac{\text{metric ton}}{10^6\ \text{gm}}\right)\left(\frac{\text{gm}}{10^3\ \text{Mg}}\right)$$

$$= 12.2\ \text{metric tons/yr}\ (13.4\ \text{tons/yr})$$

Estimates of national POM emissions from burning outcrops and abandoned mines could not be developed since no emission factor or "tonnage burning" data were available.

Prescribed Burning -- Limited data indicate that in 1976 approximately 15 million metric tons (17 million tons) of forest vegetation was consumed in prescribed burns (1). The acreage was assumed to be the same for 1980. Multiplying this figure by the 20 gm/metric ton average emission factor for wild fires presented in Section 4 results in a national POM estimate of 300 metric tons/yr (330 tons/yr).

5.2.4 Trends Influencing POM Emissions

Coal Refuse Piles, Outcrops, and Mines -- Proper enforcement of existing regulations requiring preventative disposal measures and extinguishing existing fires could substantially reduce POM emissions from coal refuse piles. However, indications are that extinguishing existing fires is difficult and costly and, as a result, has proceeded somewhat slowly (8). Also, in 1971 there were about 40 burning piles and about 160 inactive piles for which information on owners was not available. Debate over responsibility for extinguishing existing burning piles of unknown ownership could preclude quick action on these sources.

Agricultural Open Burning -- No information was located on trends in agricultural open burning. It can be hypothesized that more diligent enforcement of open burning regulations and public awareness of obvious pollution problems will tend to limit agricultural open burning to current or lower levels.

Prescribed Open Burning -- Because of its use as a wild fire prevention technique, the level of prescribed open burning is not likely to change in the near future. In the long term, continued research on fire control techniques may provide for some reduction in POM from prescribed burning.

5.3 COMBUSTION OF SOLID, LIQUID AND GASEOUS FUELS FOR HEAT AND POWER GENERATION

This section examines total POM emissions from the following combustion categories:

- utility coal, oil, and gas combustion,
- industrial coal, oil, and gas combustion,
- industrial wood combustion,
- commercial/institutional coal, oil, and gas combustion,
- residential coal, oil, and gas combustion, and
- residential wood combustion.

Combustion of municipal solid waste and industial waste is covered in Section 5.8. Only combustion in boilers and residential furnaces, stoves and fireplaces is included in this study. Process heat sources were not covered due to a lack of readily available POM emission factor data. However, coal- and oil-fired process heaters are a potential source of POM.

A general principal applicable to all these combustion sources is that more efficient combustion reduces POM formation (9). Therefore, as discussed in detail later in this section, POM emission factors (POM emitted per unit heat input of fuel) are significantly less for utility combustion sources than for less efficient residential stoves.

The following factors act to increase POM formation in combustion sources (10):

- high carbon to hydrogen ratio and high concentrations of oxygen and aromatics in the fuel,
- low temperatures in the combustion and post-combustion zone,
- short residence time of combustion gases in the combustion chamber,
- inefficient fuel/air mixing and lower air/fuel ratios,
- high frequency of start-up and shut-down, and
- larger (solid fuel) feed size.

POM emission rates from combustion sources are highly variable and, as indicated by the factors listed above, are tied directly to fuel type and the design and operation of the combustor.

5.3.1 Source Category Description

5.3.1.1 Process Description

POM compounds are formed in the gaseous phase in the combustion zone. As the combustion off-gases cool, some POM compounds condense onto particles present in the gas stream. POM is more likely to condense onto the smaller particles in the gas stream because of the larger surface area-to-volume ratios of small particles (11). At normal flue gas stack temperatures of about ~150°C (300°F), significant amounts of POM reportedly exists as vapor (9,11).

Utility Combustion

Utility coal-fired power plants burn crushed or pulverized coal to generate steam, which is in turn used to generate electric power. The common utility boiler types are:

- pulverized dry bottom (vertically-, front wall-, or tangentially-fired),
- pulverized wet bottom (opposed-fired),
- cyclone (crushed coal), and
- spreader stokers (generally used at smaller, older utilities),

Pulverized dry bottom boilers are the most commonly used, accounting for about 76 percent of bituminous coal consumption by utilities in 1978 (12). Reported POM emission factors vary somewhat between these boiler types (13).

In 1980, utilities firing coal, oil, and gas together accounted for approximately 69 percent of the installed nameplate capacity of electric utilities (14). On a heat input basis, the 1980 distribution of utility consumption of these fuels is shown in Table 5-3.

The figure for coal includes consumption of lignite and anthracite.

Industrial Combustion

Boilers are used in industry primarily to generate process steam and to provide for space heating. Some industrial boilers are also used for electricity generation. Industrial boilers are widely used in the manufacturing, processing, mining, and refining sectors.

Coal-fired industrial boilers are generally watertube designs. Firing mechanisms include pulverized coal and stoker (spreader, underfeed and overfeed stoker). Most industrial boilers are front-wall fired (16). Large

TABLE 5-3. BREAKDOWN OF FOSSIL FUEL USE IN COMBUSTION SOURCE CATEGORIES 1981 DATA

Category	Percent of Total Fossil Fuel Consumed in Category Accounted for by[c]: Coal[a]	Oil[b]	Natural Gas	Reference
Utility Boilers	66	13	21	15
Industrial Boilers	18	17	65	17
Commercial/Institutional Boilers	3	17	80	18
Residential Furnaces and Stoves	1	21	78	21

[a] Coal figure includes lignite and anthracite.

[b] Oil consumed in utility and industrial boilers is primarily No. 6 residual oil; distillate oil is primarily burned in residential furnaces.

[c] Heat input basis.

industrial boilers are commonly pulverized coal-fired, while underfeed and overfeed stokers are usually smaller units. Spreader stokers are found across the entire industrial boiler size range.

Oil and natural gas are also burned in industrial boilers. Both water tube and firetube designs are common for combustion of oil and gas.

The estimated 1980 distribution of coal, oil, and gas consumption in industrial boilers is shown in Table 5-3.

These data indicate that coal accounts for a much smaller percentage of boiler fossil fuel consumption in the industrial boiler category than in utility boilers.

Dry or wet wood can be burned in stoker-fired industrial boilers. Often these boilers are equipped with multi cyclones (mechanical collectors) which are used to capture large, partially burned particulate for reinjection to the boiler.

Commercial/Institutional Combustion

Boilers and furnaces at commercial and institutional facilities are used primarily to provide space heat. The commercial/institutional category is defined to include such facilities as hospitals, schools, office buildings, and apartment buildings. The boilers are generally smaller firetube and cast iron designs. Coal-fired units are small stokers. The 1980 distribution of coal, oil, and gas consumed in this sector is shown in Table 5-3.

These data indicate that coal consumption is low relative to oil and gas use in the commercial/institutional category.

Residential Combustion

Coal-, oil-, and gas-fired furnaces, coal- and wood-fired stoves and fireplaces are all used to heat homes. Combustion of coal and wood in domestic stoves is a slow, low temperature, inefficient process (19). As discussed above, inefficient combustion generally leads to higher POM emissions on a heat input basis.

Residential coal-fired furnaces are usually underfeed or hand-stoked units; oil-fired home furnaces use pressure or vaporization to atomize the fuel; and air is premixed with the gas before the burner in residential gas furnaces (20). Some types of wood stoves are more efficient than others due to differences in sealing of the chamber and control of the intake and exhaust systems.

The estimated 1980 distribution of residential coal, oil, and gas consumption is shown in Table 5-3.

Wood consumption in residential units is discussed in Section 5.3.3.

5.3.1.2 Emission Controls/Regulations

This subsection provides a brief overview of the particulate, SO_2, and NO_x emission controls typically applied to utility, industrial, commercial/institutional, and residential combustion sources. Available qualitative information on the indirect effect of these emission control technologies on POM emissions is also presented. Little quantitative data were located, but some qualitative assessments can be made. In addition, a simplified discussion of air emission regulations applicable to these combustion sources is provided. Table 5-4 summarizes the controls and regulations for the various combustion categories being considered. A detailed analysis of the current use of emission controls on combustion sources and applicable regulatory requirements is beyond the scope of this study.

TABLE 5-4. SUMMARY OF EMISSION CONTROLS AND REGULATIONS FOR COMBUSTION SOURCES[a]

	Existing Units		New Units	
Source Type	Typical Controls Used[b]	Applicable Regulations	Controls Likely to be Used	Applicable Regulations
Utility				
Coal	PM:[c] ESPs;[d] wet scrubbers; or fabric filters	SIPs; 1971 NSPS[e]	Fabric filters or high efficiency ESPs	1979 NSPS[f]
	SO_2: Uncontrolled; compliance coal; or FGD systems	SIPs; 1971 NSPS[e]	FGD systems	1979 NSPS[f]
Oil	PM: Uncontrolled or ESPs	SIPs; 1971 NSPS[e]	Low ash oil or ESP	1979 NSPS[f]
	SO_2: Uncontrolled or compliance oil	SIPs: 1971 NSPS[e]	Low sulfur oil	1979 NSPS[f]
Gas	PM, SO_2: Uncontrolled	g	Uncontrolled	g
Industrial				
Coal	PM: ESPs;[c] mechanical collectors; or fabric filters	SIPs; 1971 NSPS for large boilers[h]	ESPs or fabric filters, possibly side stream separators[i]	SIPs; Pending NSPS[i]
	SO_2: Uncontrolled; compliance coal; or FGD (few systems)	SIPs; 1971 NSPS for large boilers[h]	Compliance coal; some FGD systems	SIPs
Oil	PM: Uncontrolled	SIPs	Uncontrolled; low ash oil	SIPs; Pending NSPS[i]
	SO_2: Uncontrolled or compliance oil	SIPs	Compliance oil	SIPs; Pending NSPS[i]
Gas	PM, SO_2: Uncontrolled	g	Uncontrolled	
Wood	PM: ESPs; wet scrubbers; or mechanical collectors	SIPs	ESPs or wet scrubbers	SIPs; Pending NSPS[i]
	SO_2: Uncontrolled	g	Uncontrolled	g

(Continued)

TABLE 5-4. SUMMARY OF EMISSION CONTROLS AND REGULATIONS FOR COMBUSTION SOURCES[a] (Continued)

	Existing Units		New Units	
Source Type	Typical Controls Used[b]	Applicable Regulations	Controls Likely to be Used	Applicable Regulations
Commercial/Institutional				
Coal	PM: Mechanical collectors	SIPs[j]	Mechanical collectors or side stream separators	SIPs;[j] Pending NSPS[i,j]
	SO_2: Uncontrolled	SIPs[j]	Uncontrolled or compliance coal	SIPs[j]
Oil	PM, SO_2: Uncontrolled	SIPs[j]	Uncontrolled or compliance oil	SIPs[j]
Gas	PM, SO_2: Uncontrolled	g	Uncontrolled	g
Residential				
Coal, Oil, Gas, and Wood	Uncontrolled	None	Uncontrolled	None

[a] Only SO_2 and particulate emissions covered, since potentially applicable control technologies for these pollutants (FGD systems, ESPs, fabric filters) will have the most potential for indirect control of POM. However, as discussed in text, combustion modifications for NO_x may have some impact on POM emissions since they impact combustion conditions. This impact is expected to be small in relation to effect of SO_2 and PM controls, however.

[b] Intended only to cover types of control used on majority of existing sources based on a qualitative assessment.

[c] PM: particulate matter.

[d] Range of efficiencies low (~80%) to high (95% or greater).

[e] 1971 NSPS (40 CFR60 Subpart D) requires the following for utility boilers and industrial boilers with a heat input capacity of 73 MW_t (250 million Btu/hr) or greater constructed after August 17, 1971:

PM : 43 ng/J (0.1 lb/million Btu) emission limit; 20% opacity
SO_2: 520 ng/J (1.2 lb/million Btu) emission limit for coal
340 ng/J (0.8 lb/million Btu) emission limit for oil

[f] 1979 NSPS (applies only to utility boilers) requires the following for units constructed after September 18, 1978:

PM : 13 ng/J (0.03 lb/million Btu) emission limit: 20% opacity for all fuels

SO_2: 520 ng/J (1.2 lb/million Btu) and 70 to 90 percent SO_2 removal for coal
-340 ng/J (0.8 lb/million Btu) for oil and 90 percent SO_2 removal down to 86 ng/J (0.2 lb/10^6 Btu)

[g] Emissions of PM and SO_2 from gas-fired boilers and SO_2 emissions from wood-fired boilers are small and are not generally regulated.

[h] Large boilers are those with a heat input capacity of 73 MW_t (250 million Btu/hr) or greater.

[i] EPA is developing an NSPS for industrial and commercial/institutional boilers with heat inputs of 14.7 MW_t (50 million Btu/hr) or greater. The NSPS is tentatively scheduled to be proposed within a year. Most recent favored alternative is based on fabric filter or ESPs down to 29 MW, but side stream separators have also been considered (for coal-fired boilers).

[j] May not apply to C/I units below a certain size cutoff.

Unfortunately, without detailed information on the application of emission control technologies and quantitative data describing indirect effect of particulate, SO_2, or NO_x controls on POM emissions, the accuracy of national emission estimates developed in Section 5.3.3 is questionable. However, an effort has been made to use published emission factors that were judged to be fairly representative of the current population of combustion sources, including the type of emission controls used. The estimated accuracy of the national emission estimates is discussed further in Section 5.3.3.

Utility Combustion

Utility coal-fired boilers constructed in the last 10 to 12 years are required to use control measures to limit SO_2, particulate matter, and NO_x emissions. Older coal-fired utilities are generally equipped only with particulate control devices. POM emissions are likely to be affected to some degree by particulate, SO_2, and NO_x control systems.

Some POM compounds condense onto particulate matter at normal flue gas temperatures encountered in utility boilers. As discussed above, the compounds tend to condense on smaller (fine) particles. Therefore, particulate emission control devices that are efficient collectors of fine particles will provide a significant degree of control of the POM associated with particulate matter. Fabric filters and ESPs are high efficiency particulate control techniques applied to the current population of utility boilers. (Fabric filters are used only on relatively new utility boilers.) The fine particle collection efficiencies of ESPs currently in use will often depend on the age of the boiler. Older boilers are generally subject to less stringent air emission regulations, and ESPs applied to these units are likely to exhibit lower fine particle collection efficiencies.

Wet scrubbers and multicylcones are also used on some existing utility boilers for particulate control. Low-energy wet scrubbers (low pressure drop) have lower fine particulate collection efficiencies than high-energy venturi-type scrubbers. However, it should be noted that wet scrubbers may be more effective in reducing POM emissions than "dry" control systems because those POM compounds existing as vapors would be condensed and collected as the gas is saturated in the scrubber.

Multicyclones, which may still be in use as the sole particulate control device on a few old utility boilers, are not efficient collectors of fine particles, and are therefore not expected to significantly reduce POM emissions.

The most common SO_2 control technology currently used on utility coal-fired boilers is lime/limestone flue gas desulfurization (FGD). This technique employs a wet scrubber, which is often preceeded by an ESP. The ESP collects the particulate before the flue gas enters the FGD system. Wet FGD/ESP systems, while providing for control of POM condensed on particulate at the entrance to the ESP, are not likely to achieve significant control of vapor phase POM (22). Condensation of vapor phase POM compounds will occur in the wet scrubber, but significant collection of particles remaining in the gas flow through the scrubber is not likely to occur. Systems equipped with mist eliminators may exhibit a slight reduction in particulate before the stack. There were 94 operating utility wet FGD systems as of January 1982 (about 13% of installed coal-fired capacity) (23).

A more recently applied utility SO_2 control technique is spray drying. In this process, the gas is cooled in the spray dryer but remains above the saturation temperature. A fabric filter or an ESP is located downstream of the spray dryer. Thus, this system would provide for significant control of both particulate and vapor phase POM because the vapor phase compounds are condensed before they reach the high efficiency particulate control device. One source (22) estimated that over 90 percent of the benzo(a)pyrene emitted from a representative utility boiler would be controlled by a spray dryer FGD system. As of early 1983, there were five utility spray drying systems, all applied to new units in the initial phases of commercial operation (24).

Nitrogen oxide control techniques applied to newer coal-fired boilers include low-excess air firing and staged combustion. The principle of these control techniques is to limit the oxygen available for NO_x formation in the combustion zone. However, as discussed in Section 5.3.1.1, lower air to fuel ratios may lead to increased POM formation (other conditions remaining constant). Data regarding the effects of "low-NO_x" operating conditions on POM formation is conflicting and very limited (25).

The POM emission factors that have been reported for utility boilers have either been based on data from uncontrolled boilers or on measurements made downstream of an emission control device. No emission data were located that included simultaneous POM measurement both before and after the control device. Thus, it is difficult to quantify the impact of the technology on POM emissions.

Air emission regulations applicable to existing coal-fired utility boilers include SIP emission limits and the 1971 and 1979 NSPS (Subparts D and Da, respectively, of 40 CFR 60). The 1971 NSPS applies to boilers constructed after August 1971. That standard specifies a 520 ng/J (1.2 lb/million Btu) SO_2 emission limit and a 43 ng/J (0.1 lb/million Btu) particulate matter emission limit. The 1979 NSPS, which applies only to units constructed after September 1979, is more stringent, requiring 70 to 90 percent SO_2 removal and a specifying a 13 ng/J (0.03 lb/million Btu) particulate emission limit (26). Under this NSPS, new coal-fired utility boilers will generally be required to be equipped with fabric filters or high efficiency ESPs and FGD systems. The 1979 NSPS also requires the use of NO_x control techniques.

Existing oil-fired utility boilers are generally either uncontrolled or are equipped with ESPs for particulate emission control. The same considerations discussed above for ESPs applied to coal-fired utility boilers apply to oil-fired units. SO_2 control for existing oil-fired boilers is most often achieved by the use of lower sulfur oils.

Air emission regulations applicable to oil-fired utilities include the 1971 and 1979 NSPS and SIP requirements.

Gas-fired utility boilers are not equipped with emission controls since SO_2, particulate, and NO_x emissions from these units are relatively low.

Industrial Combustion Sources

Emission control techniques for industrial coal-fired boilers are similar to those described for utility coal-fired units. However, application of SO_2 and particulate control technologies to the current population of industrial boilers differs substantially with the application of these controls to utility boilers. There are very few industrial boilers equipped with FGD systems for SO_2 control. Fewer than 15 lime/limestone or double alkali systems are operating on industrial coal-fired boilers. There are about 12 sodium-based FGD systems operating on coal-fired boilers, primarily at paper mills and textile plants (27). Five spray drying FGD systems have begun operation in the last few years (28). However, most existing coal-fired industrial boilers meet applicable SO_2 regulations by burning low or medium sulfur coal.

The use of particulate control on industrial boilers is more common. Existing industrial coal-fired units are subject to SIP particulate matter emission limits. For a 44 MW_t boiler, these limits vary from 22 ng/J (0.05 lb/million Btu) in California to 344 ng/J (0.8 lb/million Btu) in Iowa (24). Most SIPs fall in the 86 to 172 ng/J (0.2 to 0.4 lb/million Btu) range, which generally requires the use of a low-efficiency ESP or a multicyclone collector. SIP emission limits for larger industrial boilers ($\geq$73MW_t) are more stringent, often specifying a 43 to 86 ng/J (0.1 to 0.2 lb/million Btu) emission limit. Medium- and high-efficiency ESPs are required to comply with such regulations. Finally, unless the SIP is more stringent, large industrial coal-fired boilers ($\geq$73 MW_t) constructed after August 1971 are subject to an existing NSPS which specifies a 43 ng/J (0.1 lb/million Btu) particulate matter emission limit. Fabric filters or ESPs are commonly used to meet this standard.

As of December 1979, 104 industrial boilers were using or planning to use fabric filters (30). No comparable data were located on the number of ESPs, wet scrubbers, or multicyclones applied to industrial units, although the use of ESPs on existing boilers is considered to be substantially more widespread than the use of fabric filters (29). Wet scrubbers are not generally used for particulate control on coal-fired boilers because they result in a liquid waste stream that must be disposed of properly (29).

A relatively new particulate control technology, applicable to stoker-fired industrial boilers, is the side stream separator. This device is a multicyclone modified to treat part of the gas in a small fabric filter. The fabric filter enhances the overall collection efficiency of the multicyclone by removing a portion of the fine particulate (31). To date, side stream separators have been retrofitted to only a few existing stoker-fired boilers (31).

An NSPS currently being developed by EPA may require that fabric filters or ESPs be applied to all new coal-fired industrial boilers above about 29 MW (100×10^6 Btu/hr). At a minimum, the NSPS will require use of side stream separators. The NSPS is also likely to require low excess air or staged combustion for control of NO_x emissions. At this time, the standard being developed contains no provision for SO_2 control. The NSPS may be proposed as early as the summer of 1983.

Particulate emissions from oil-fired industrial boilers are generally not controlled under current regulations. However, oil sulfur content restrictions do apply to some existing units. New oil-fired boilers will be subject to the NSPS being developed by EPA, which may require some degree of particulate emission control.

Multicyclones followed by venturi or impingment-type wet scrubbers are the most common type of particulate matter control devices applied to wood-fired boilers (32). The same considerations discussed above for wet scrubbers used on coal-fired boilers apply to the use of the technology on wood-fired boilers. However, the use of wet scrubbers is more common for wood-fired units than for coal because wood-fired units are often located at paper mills or other facilities with existing equipment that can be used to dispose of the liquid waste stream from the scrubber. ESPs are also used to some extent on wood-fired boilers. The use of fabric filters, however, is restricted to those boilers firing a salt-laden type of wood because of potential fabric filter fire hazards associated with combustion of other types of wood (32).

Wood-fired boilers are currently subject only to SIP emission limits. Forty-three states have SIP limits for particulate emissions from wood-fired boilers (40). These emission limits are about the same as those in SIPs applicable to coal-fired units.

Commercial/Institutional Combustion

Commercial and institutional boilers are generally uncontrolled or equipped only with multicyclones (mechanical collectors) for particulate matter control. As previously discussed, multicyclones are not efficient collectors of the fine particles with which POM compounds are generally associated.

Commercial and institutional units may be subject to SIP particulate emission limits in states that do not specifically define their regulations as applicable only to industrial boilers. Most SIP particulate emission limits are a function of boiler size and regulations are significantly less stringent for small sources. New commercial/institutional boilers with greater than 14.7 MW_t (50 million Btu/hr) heat input capacity will be subject to the NSPS currently being developed for industrial boilers (33).

Residential Combustion

Residential combustion sources are not equipped with add-on particulate matter control devices. Combustion modifications designed to improve the efficiency of coal- and wood-fired residential stoves have not been extensively applied to commercially available stoves (25). Most of the combustion modifications applicable to residential stoves are in the form of stove design changes and include modified combustion air flow control, better thermal control and heat storage, and the use of catalytic combustors.

The sulfur content of the coal burned in residential units is regulated in some areas, but in general residential combustion units are not subject to Federal or state air emission regulations.

5.3.1.3 Source Locations

Utility Combustion

Table 5-5 shows the existing utility capacity by fuel type for each of the 50 states. Existing capacity for specific fuels is expressed in MW electrical output and as a percentage of the total existing capacity for that fuel.

These data indicate several well-established trends:

- Coal-fired units are concentrated in the states of Ohio, Indiana, Pennsylvania, and Illinois. Other states with substantial coal-fired capacity are Alabama, Georgia, Kentucky, Michigan, Missouri, North Carolina, Tennessee, Texas (lignite), and West Virginia.
- Residual oil-fired units are found primarily in California, Florida, and New York. It should be noted that in contrast to the installed capacity data in Table 5-4, 1980 fuel consumption data for utilities show that in several states, little or no residual oil was burned by utilities (15). States which reported no oil consumption by utilities included Alabama, Indiana, Kentucky, Montana, North Dakota, Oklahoma, Vermont, West Virginia, and Wyoming. The decrease in residual oil use is likely the result of units with dual-fuel capabilities being fired with coal or natural gas as a result of the sharply increasing residual oil prices in recent years.
- Natural gas-fired units are highly concentrated in Texas (over half the installed capacity) and Louisiana.

TABLE 5-5. 1980 INSTALLED UTILITY CAPACITY BY STATE AND FUEL TYPE[a] (34)

State	Coal		Residual Oil		Natural Gas	
	MW	% U.S. Coal Capacity[b]	MW	% U.S. Oil Capacity[b]	MW	% U.S. Natural Gas Capacity [b]
Alabama	10585	3.9	148	0.10	480	0.64
Alaska	54	0.02	478	0.32	491	0.65
Arizona	4735	1.7	3247	2.2	372	0.49
Arkansas	2112	0.78	1259	0.84	1662	2.2
California	0	0	24968	16.6	510	0.68
Colorado	4512	1.7	813	0.54	287	0.38
Connecticut	0	0	3805	2.5	0	0
Delaware	743	0.27	1296	0.86	0	0
Florida	4857	1.8	21705	14.5	301	0.39
Georgia	11479	4.2	2157	1.4	5	0.01
Hawaii	0	0	1553	1.0	0	0
Idaho	0	0	8	0.01	50	0.07
Illinois	17314	6.4	6000	4.0	219	0.29
Indiana	16164	6.0	1321	0.88	93	0.13
Iowa	5614	2.1	1526	1.0	141	0.19
Kansas	4088	1.5	647	0.43	3612	4.8
Kentucky	14434	5.3	194	0.13	139	0.18
Louisiana	1118	0.41	1471	0.98	11133	14.8
Maine	0	0	1149	0.77	0	0
Maryland	3034	1.1	4309	2.9	144	0.19
Massachusetts	0	0	7389	4.9	9	0.01
Michigan	11329	4.2	4969	3.3	895	1.2
Minnesota	5076	1.9	1540	1.0	162	0.22
Mississippi	2428	0.89	902	0.60	2788	3.7
Missouri	12088	4.5	1794	1.2	1159	1.5
Montana	939	0.35	134	0.09	30	0.04
Nebraska	3055	1.1	751	0.50	509	0.68
Nevada	2248	0.83	182	0.12	1160	1.5
New Hampshire	459	0.17	709	0.47	0	0

(Continued)

TABLE 5-5. 1980 INSTALLED UTILITY CAPACITY BY STATE AND FUEL TYPE[a] (34) (Continued)

State	Coal		Residual Oil		Natural Gas	
	MW	% U.S. Coal Capacity[b]	MW	% U.S. Oil Capacity[b]	MW	% U.S. Natural Gas Capacity [b]
New Jersey	1665	0.61	8725	5.8	80	0.11
New Mexico	3473	1.3	420	0.28	1071	1.4
New York	2977	1.1	19684	13.2	99	0.13
North Carolina	11821	4.4	980	0.65	0	0
North Dakota	3233	1.2	256	0.17	10	0.01
Ohio	24031	8.8	2637	1.8	208	0.28
Oklahoma	4049	1.5	882	0.59	6184	8.2
Oregon	561	0.21	756	0.50	87	0.12
Pennsylvania	19291	7.1	7447	5.0	61	0.08
Rhode Island	0	0	282	0.19	0	0
South Carolina	4126	1.5	2397	1.6	11	0.01
South Dakota	497	0.18	321	0.21	0	0
Tennessee	10021	3.7	0	0	2036	2.7
Texas	13310[b]	4.9	3266	2.2	38494	51.1
Utah	2315	0.85	45	0.03	31	0.04
Vermont	30	0.01	155	0.10	0	0
Virginia	3488	1.3	3524	2.4	0	0
Washington	1330	0.49	246	0.16	417	0.55
West Virginia	14779	5.4	19	0.01	0	0
Wisconsin	7233	2.7	1707	1.1	174	0.23
Wyoming	5028	1.9	15	0.01	0	0
U.S. Total	271,723 MW		150,188 MW		75,314 MW	

[a] May include large industrial power plants that generate electricity.

[b] % of installed utility capacity for that fuel.

Table 5-6 shows existing capacity data for coal-, oil-, and gas-fired utilities aggregated by EPA region.

Industrial Boilers

Industrial boilers are located throughout the United States. Boiler locations tend to follow industry and population location trends. Table 5-7 shows regional industrial energy use for six major industrial sectors. Although these data represent total industrial energy consumption (i.e., electricity, raw materials, boilers, and process heat sources, they are indicative of industrial boiler geographical concentrations. Most of the coal-fired industrial boilers are in the Great Lakes, Great Plains, Appalachian, and Southeast regions. Oil-fired boilers are common in the New England, Southeast, and Upper Atlantic regions, while the highest concentration of natural-gas-fired units is found in the Gulf Coast and Pacific Southwest regions (35).

Wood-fired boilers tend to be located almost exclusively at pulp and paper, lumber products and furniture industry facilities. These industries are concentrated in the Southeast, Gulf Coast, Appalachian, and Pacific Northwest regions (35).

Commercial/Institutional Boilers

These sources are also spread throughout the United States and their concentrations are tied directly to population centers. Fuel use patterns for commercial/institutional boilers are likely to parallel those described above for industrial boilers, since fuel choice decisions in both categories are made on the basis of fuel availability and prices (including transportation).

Residential Combustion

Locations of residential combustion sources will also be directly tied to population trends, with one exception: wood-fired stoves and fireplaces. Wood-fired residential combustion sources are concentrated in heavily forested

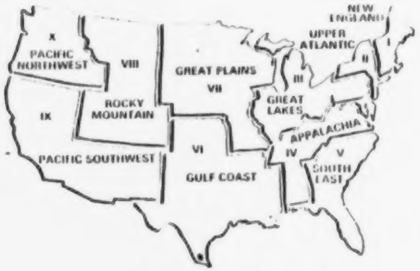
TABLE 5-6. 1980 EXISTING UTILITY CAPACITY BY EPA REGION AND FUEL TYPE[a]

EPA Region	Existing Capacity (MW)		
	Coal-Fired	Oil-Fired	Gas-Fired
1	489	13,489	9
2	4,642	28,409	179
3	41,335	16,595	205
4	69,751	28,483	5,760
5	81,147	18,174	1,751
6	24,062	7,298	58,544
7	24,845	4,718	5,421
8	16,524	1,584	358
9	6,983	29,950	2,042
10	1,945	1,488	1,045
U.S. Total	271,723	150,188	75,314

[a] Aggregated from data in Table 5-5.

TABLE 5-7. 1977 REGIONAL SHARES OF INDUSTRIAL ENERGY USE (35)

	Chemicals		Primary Metals		Petroleum/Coal		Paper		Stone/Clay/Glass		Food	
	Region %	Nation %	Region %	Nation %	Region %	Nation %	Region %	Nation %	Region %	Nation %	Region %	Nation %
New England	8	<1	6	<1	1	<1	34	7	7	3	5	3
Upper Atlantic	21	6	30	9	12	6	6	4	10	12	6	10
Great Lakes	10	10	49	57	10	19	4	10	8	33	3	20
Appalachia	30	11	29	12	3	2	17	15	6	10	3	6
Southeast	15	4	2	<1	<1	<1	45	25	6	6	5	7
Gulf Coast	52	59	5	6	27	52	6	16	3	14	2	11
Great Plains	16	3	9	2	6	2	16	7	12	9	17	17
Rocky Mountain	3	<1	51	4	26	3	<1	<1	9	3	7	3
Pacific Southwest	12	3	15	4	35	13	6	3	10	9	9	9
Pacific Northwest	7	<1	27	4	9	2	37	12	3	2	6	5



areas of the U.S. This pattern again reflects fuel selection based on availability and price (36).

Table 5-8 shows the percent of total U.S. wood consumption in fireplaces and stoves by state and by EPA region.

5.3.2 Emission Factors

Table 5-9 presents total POM emission factors for the various combustion source categories being considered in this study. Appendix A contains more detail on the bases of the emission factors shown in the table.

As noted earlier, there are several cautions that apply to the use of these emission factors as representative of POM emissions from specific boilers. The emission factors used here are intended to represent only the best available estimates of POM emission factors for the particular combustion source population as a whole and generally will not apply to specific units with a high degree of accuracy. The most important cautions regarding the emission factors presented in this section are summarized below.

Much of the data used in developing the reported emission factors was collected in the late 60's and early 70's using modified Method 5 sampling techniques. As discussed in Section 3, a reportedly significant amount of POM is present in the vapor phase at temperatures typical of utility and industrial boiler stacks. These POM compounds are unlikely to have been fully captured with the Method 5 sampling train unless relatively advanced modifications were incorporated. Thus, the POM emission factor data may represent primarily only the POM associated with particulate matter at the sampling point. Therefore, the use of these emission factors, with all other assumptions being accurate, could result in an underestimate of nationwide POM emissions from combustion sources. No useful quantitative data were found in published literature to allow estimation of how much vapor-phase POM typically escapes.

TABLE 5-8. 1981 WOOD CONSUMPTION IN FIREPLACES AND STOVES BY STATE AND EPA REGION (37)

EPA Region	State	Wood Consumption (% of U.S. Total)[a]
Region 1	Connecticut	1.6
	Maine	1.6
	Massachusetts	2.3
	New Hampshire	0.89
	Rhode Island	0.29
	Vermont	0.82
	Regional Total	7.4
Region 2	New Jersey	2.3
	New York	5.6
	Regional Total	7.9
Region 3	Delaware	0.35
	Maryland	2.3
	Pennsylvania	6.3
	Virginia	4.8
	West Virginia	2.0
	District of Columbia	0.03
	Regional Total	15.7
Region 4	Alabama	1.5
	Florida	1.7
	Georgia	2.1
	Kentucky	3.1
	Mississippi	1.3
	North Carolina	5.9
	South Carolina	1.3
	Tennessee	4.3
	Regional Total	21.0
Region 5	Illinois	3.8
	Indiana	3.4
	Michigan	4.5
	Minnesota	3.0
	Ohio	5.3
	Wisconsin	3.1
	Regional Total	23.1

(Continued)

TABLE 5-8. 1981 WOOD CONSUMPTION IN FIREPLACES AND STOVES BY STATE AND EPA REGION (37) (Continued)

EPA Region	State	Wood Consumption (% of U.S. Total)[a]
Region 6	Arkansas	1.2
	Louisiana	0.79
	New Mexico	0.98
	Oklahoma	1.8
	Texas	1.2
	Regional Total	6.0
Region 7	Iowa	0.36
	Kansas	0.32
	Missouri	3.7
	Nebraska	0.19
	Regional Total	4.6
Region 8	Colorado	1.2
	Montana	0.83
	North Dakota	0.07
	South Dakota	0.12
	Utah	0.49
	Wyoming	0.31
	Regional Total	3.0
Region 9	Arizona	0.57
	California	5.1
	Hawaii	<0.01
	Nevada	0.26
	Regional Total	6.0
Region 10	Alaska	0.39
	Idaho	0.83
	Oregon	2.0
	Washington	2.3
	Regional Total	5.4

[a] % of total U.S. wood consumption in fireplaces and stoves.

TABLE 5-9. TOTAL POM EMISSION FACTORS FOR COMBUSTION SOURCE CATEGORIES[a]

Source Category	Reported Emission Factor[b]	Converted to Heat Input Basis[c] pg/J (lb/Btu × 10^{12})	Emission Control Level Represented[d]	Emission Factor Basis[e]
Utility Combustion				
Coal	19 μg/kg	0.71 (1.65)	"Controlled" (ESP)	1
Oil	2 × 10^{-6} lb/10^6 Btu	0.86 (2.00)[i]	None	3
Gas	DNL[f]	--	--	-
Industrial Combustion				
Coal	41 μg/kg	1.53 (3.57)	Multicyclone	1
Oil	21 μg/ℓ	0.50 (1.17)	None	3
Gas	11 μg/m^3	0.30 (0.69)	None	3
Wood	2059 μg/kg	105 (242)	h	2
Commercial/Institutional Combustion				
Coal	DNL[g]	--	--	-
Oil[j]	21 μg/ℓ	0.50 (1.17)	None	3
Gas[j]	11 μg/m^3	0.30 (0.69)	None	3
Residential Combustion				
Coal	67 mg/kg	2500 (5826)	None	2
Oil	120 μg/ℓ	2.86 (6.67)	None	2
Gas	65 μg/m^3	1.74 (4.06)	None	2
Wood Stoves	0.27 g/kg[k]	13,472 (31,435)	None	2
Wood Fireplaces	0.029 g/kg	1447 (3375)	None	3

[a] More detail on each of these emission factors can be found in Appendix A. All emission factors are from Reference 1, Table III-1 ("Intermediate" factors were used) except for emissions for oil-fired utilities (Ref 38), wood-fired industrial boilers (Ref 39), and wood-fired residential units (Ref 36).

[b] Units reported in reference cited (Mass of POM emitted per unit of fuel burned).

[c] See Appendix A for sample calculation. Fuel heating values assumed for conversions: Coal = 11,500 Btu/lb; Oil = 150,000 Btu/gal; Gas = 35,300 Btu/m^3; and Wood = 8600 Btu/lb.

[d] As reported in reference cited for emission factor.

[e] 1 = weighted average reflecting boiler population.
2 = arithmetic or geometric average of boiler types.
3 = one facility.

[f] DNL = Data not located. The emission factor for gas-fired utilities is expected to be lower than for coal or oil because of the high efficiency combustion achieved in gas-fired utility boilers. Notice that the emission factor for industrial boiler gas combustion is significantly lower than for industrial oil-fired boilers.

[g] The emission factor for commercial/institutional coal combustion is expected to be higher than for utilities due to the larger fuel feed size and less efficient combustion associated with commercial units.

[h] The emission factor represents an average of data for 7 wood-fired industrial boilers, 3 with mechanical collectors and 4 uncontrolled. On controlled units, emissions were measured downstream of the collection device.

[i] The fact that the estimated emission factor for oil is higher than for coal may reflect the fact that ESPs applied to coal-fired units achieve a certain degree of fine particle (and thus POM) control. The reported emission factor for the oil-fired utility boiler reflects a "no control" situation.

[j] The emission factors reported for industrial oil- and gas-fired boilers were used for commercial/instutional oil- and gas-fired boilers, since the industrial boilers tested were relatively small and representative of commercial/institutional units.

[k] Range of POM emission factors reported in literature was 0.05 to .37 g/kg of wood burned. The emission factor selected represents an average of six well-documented tests on representative stoves.

The methods used in past source tests to sample for and analyze POM compounds from combustion sources have varied considerably with respect to sample collection, preservation, and preparation, and with respect to component analysis techniques. Thus, it is difficult to develop valid comparisons between emission factor data for various source categories. One must rely to a large degree on the theoretical principles that describe POM formation in combustion sources in assessing the relative potential for various categories to be significant sources of POM emissions.

Boiler design and operating parameters (including firing method, combustion zone temperatures, fuel/air mixing parameters, fuel/air ratio, and fuel properties) influence POM formation and emissions. Other factors being constant, boilers that are designed and operated in a manner that maximizes combustion efficiency may have lower POM emission factors than inefficiently operated units. However, quantitative data on boiler design and operating practices for specific boiler categories and the relative effect of these practices on POM emissions are lacking. The best emission factors for the purposes of this study were considered to be those which reflected a "weighted average" of emission factors for the boiler population. These factors were available only for coal-fired utility and industrial boilers. Other published emission factors represented arithmetic or geometric averages of emission factors for various boiler types within a category. And, in some instances, available emission factors were based only on data from one facility.

Details on the type of emission control equipment used on the sources tested and on the design and operating parameters of the control equipment were not typically included with the "controlled" emission factor data reported in the literature. Clearly, these parameters would be useful in determining how representative the sources tested are with respect to the current boiler population. Furthermore, quantitative data on the effect of particulate matter, SO_2, and NO_x control devices on POM emissions were not located in the literature reviewed. Therefore, it was not feasible to use uncontrolled POM emission factors combined with estimated POM removal efficiencies of the control devices currently in use to develop total emissions.

Despite these caveats, the national emission estimates presented in the next section should be useful for preliminary evaluations of POM source categories. They will be most useful in pinpointing combustion source categories with the greatest potential for POM emissions. They are also appropriate for providing an idea of the amount of POM that could be controlled by regulating various categories.

5.3.3 National Emission Estimates

Table 5-10 shows 1980 national estimated POM emissions from the various combustion source categories considered in this study. The emission factors and fuel consumption data used to calculate the national emissions are also shown.

Estimated total POM emissions from wood-fired stoves account for 90 percent of annual POM emissions from all combustion sources. The emission factor for wood stoves is four to five orders of magnitude higher than those for virtually all other combustion sources except coal-fired stoves and wood fireplaces. The higher POM emission factor is attributable to highly inefficient combustion in wood stoves.

The next most significant combustion source categories of POM are residential coal stoves and wood-burning fireplaces, which together account for 8.6 percent of the toal estimated POM from combustion sources. Thus, residential sources are estimated to account for 99 percent of POM emissions from fuel combustion.

In terms of absolute magnitude of emissions, the other significant combustion source category is wood-fired industrial boilers. However, emissions from this category may be over-estimated somewhat because they are based on a POM emission factor that represents only the application of mechanical collector particulate emission controls. Many of the larger wood-fired boilers are equipped with ESP or wet scrubbers which could provide significantly more POM control than mechanical collectors. These same cautions about overstating

TABLE 5-10. 1980 NATIONAL TOTAL POM EMISSIONS ESTIMATES FOR COMBUSTION SOURCES

Source Category	Estimated 1980 U.S. Fuel Consumption 10^{15}J (10^{12} Btu)[a]	Emission Factor pg/J (lb/10^{12} Btu)	National Emissions Mg/yr (tpy)	% of Total from Combustion Sources
Utility Combustion				
Coal	12,855 (12,150)	0.71 (1.65)	9.1 (10.0)	0.12
Oil	2592 (2450)	0.86 (2.00)	2.2 (2.4)	0.03
Gas	4031 (3810)	0.52 (1.2) est.[b]	2.1 (2.3)	0.03
				(0.18)
Industrial Combustion				
Coal	1009 (954)[e]	1.53 (3.57)	1.5 (1.7)	0.02
Oil	959 (906)[e]	0.50 (1.17)	0.48 (0.53)	0.01
Gas	3555 (3360)[e]	0.30 (0.69)	1.1 (1.2)	0.01
Wood	579 (547)[f]	103 (237)	59.6 (65.6)	0.76
				(0.80)
Commercial/Institutional Combustion				
Coal	100 (94.7)[g]	1.7 (4.0) est.[c]	0.17 (0.19)	neg
Oil	599 (566)	0.50 (1.17)	0.30 (0.33)	neg
Gas	2825 (2670)	0.30 (0.69)	0.84 (0.92)	neg
				neg
Residential Combustion				
Coal	68.8 (65.0)	2500 (5826)	172 (189)	2.2
Oil	1310 (1241)	2.86 (6.67)	3.8 (4.2)	0.05
Gas	5152 (4870)	1.74 (4.06)	14.7 (16.2)	0.19
Wood Stoves	520 (492)[h]	13,500 (31,400)[d]	7022 (7733)	90.1
Wood Fireplaces	346 (328)[h]	1450 (3370)[d]	502 (553)	6.4
				(99.0)
TOTAL			7792 (8581)	100.0

[a] Reference 15, pp. 5-9, except as noted. More data on fuel consumption estimates can be found in Appendix A.

[b] Estimated based on the difference between reported emission factors for oil- and gas-fired industrial boilers.

[c] Esimated to be slightly higher than emission factor for coal-fired industrial boilers.

[d] Rounded to 3 significant figures from Table 5-9.

[e] Total industrial fuel consumption values from Reference 15 adjusted to reflect only amount used in boilers. (See Reference 17 note.) Adjustment factors (% total consumption used in boilers): Coal - 30%; Oil - 67%; and Gas - 40%.

[f] Reference 40. Total estimated heat input capacity for wood-fired boilers multiplied by 60% load factor to determine annual Btu consumption.

[g] All reported commercial/institutional combustion assumed to be in boilers.

[h] Reference 37.

emissions also apply to those estimates presented in Table 5-10 for industrial coal-fired boilers. However, as discussed previously, the published POM emission factor data used may not reflect that portion of POM emitted as vapor at typical stack temperatures, thus underestimating actual POM emissions from a single boiler.

The estimates in Table 5-10 indicate that utility boilers account for only about 0.2 percent of total POM emissions from the combustion source categories examined. There is, however, substantial uncertainty related to (1) the POM emission factor data, (2) the (indirect) effect of particulate and SO_2 controls on POM emissions, and (3) the fuel consumption data used in developing the national estimates. Thus, it is appropriate to conduct a sensitivity analysis using the extremes of reported data and making some "worst-case" assumptions. For example, one recently debated topic is the potential impact on POM emissions of existing oil- and gas-fired utilities converting to coal. These concerns are related to the fact that combustion of coal results in higher POM emissions per unit heat input than combustion of oil or gas in similar units.

In the "worst case", assume that all 1980 fuel consumption by utilities was in the form of coal (about 19,500 x 10^{15}J based on Table 5-10). By multiplying this consumption by the highest POM emission factor for pulverized coal combustion in utility units (controlled with an ESP, since coal conversions would likely be subject to at least SIP particulate emission limits), a "worst case" estimate can be developed:

$$\left(1.0\ \frac{\text{pg}\quad\text{POM}}{\text{J coal burned}}\right)\left(\frac{19{,}500 \times 10^{15}\text{J}}{\text{Yr}}\right)\left(\frac{\text{metric ton}}{10^{18}\ \text{pg}}\right) = 19.5\ \frac{\text{metric tons}}{\text{Yr}}\ \text{POM}$$

[This emission factor is the "maximum" reported in Reference 1, Table III-1, converted to pg/J using a coal heating value of 26,800 kJ/kg (11,500 Btu/lb)]. Even with these worst case assumptions, emissions from the utility category would be only about 0.26 percent of the estimated total for combustion categories.

Another category where a sensitivity analysis is appropriate is combustion of wood in residential stoves. Emission factors for POM reported in the literature ranged from 0.05 to 0.37 g/kg wood burned (References 42 and 36, respectively). Using these emission factors and the fuel consumption data shown in Table 5-10, a range of estimates between 1300 and 9600 metric tons per year can be developed [based on a wood heating value of about 20,041 kJ/kg (8600 Btu/lb of dry wood.)] The fact that such a range exists is clearly indicative of the variability and uncertainty of POM emission factors and the associated impact on the relative significance of various source categories.

Table 5-11 presents a limited comparison of national emission estimates developed in this study with previously published estimates. It is beyond the scope of this study to investigate the differences between these estimates in detail. However, the estimates appear to be relatively consistent with two exceptions. Reference 36 reports significantly higher emissions from coal-fired industrial boilers. The estimate was based on a 56 pg/J emission factor, versus 1.5 pg/J reported in Reference 1, and was representative only of a pulverized dry bottom industrial boiler. The 1.5 pg/J factor appears to be more representative. It is about twice the emission factor reported for utility pulverized coal units, reflecting primarily the difference in emission control device application between the utility and industrial sectors. Another indication that emissions from coal-fired utility and industrial boilers are similar is benzo(a)pyrene (BaP) emission data reported in Reference 2. The BaP factor for utility coal combustion was reported to be about 0.05 pg/J and for industrial units it was reported to be about 0.03 pg/J.

The other discrepancy observed in Table 5-11 is the difference in estimates for wood stoves. However, this difference can be accounted for by the differences in fuel consumption data used to develop the estimates. Reference 36 estimated 1976 residential wood combustion at about 16 million metric tons. However, recent data for 1980 indicate that that figure has increased to about 26 million metric tons (37). More information on trends in residential wood combustion is presented in Section 5.3.4.

TABLE 5-11. COMPARISON OF TOTAL POM EMISSION ESTIMATES WITH THOSE REPORTED IN PREVIOUS STUDIES

Combustion Source Category	Estimate in Current Study 1980 (metric tons/yr)	Reference 36 ~1976 (metric tons/yr)	Reference 41 ~1976 (metric tons/yr)
Utility			
Coal	9.1	12.9	9.5
Oil	2.2	0.3	0.3
Gas	2.1	0.3	0.3
Industrial			
Coal	1.5	69.0[a]	15.7
Oil	0.48	1.3	1.2
Gas	1.1	2.1	2.0
Wood	59.6	1.2	DNR
Commercial/ Institutional		DNR	
Coal	0.17		3.1
Oil	0.30		1.8
Gas	0.84		1.2
Residential			
Coal	172	102	3664[b]
Oil	7.2	7.4	4.7
Gas	14.7	9.8	5.7
Wood Stoves	7022	3759[c]	69.8
Wood Fireplaces	502	78	
Total	7795	4042	3779[d]

[a] Emissions reported in Ref. 36 based solely on pulverized coal dry bottom boiler, emission factor of 56 pg/J versus 1.5 pg/J as reported in Reference 1 as an average for all boiler types. The 1.5 pg/J emission factor is about twice that reported for coal-fired utility units, reflecting primarily the difference in control devices (See Table 5-9).

[b] No documentation of emission factor or production data used to calculate emissions

[c] Based on about 16 million metric tons of wood consumed in 1976, vs. 1980 consumption which was about 26 million metric tons.

[d] No documentation of emission factor or production data accompanied report.

One final consideration that should be kept in mind when reviewing the national estimates is that emissions from residential combustion sources used for heating vary considerably with respect to the season. An example of this variation is shown in Figure 5-1 for wood consumption in fireplaces and stoves. These data show the difference in wood consumption and estimated POM emisions between winter and summer months. Similar trends can be expected for emissions from residential coal, oil, and gas combustion sources used primarily for heating.

5.3.4 Trends Influencing POM Emissions

Utility Combustion - POM emissions from utility combustion will be influenced primarily by three factors: the type of fuel burned, emission controls used, and growth in new plant construction.

With respect to the type of fuel burned, the brief sensitivity analysis described above indicates that even if all existing oil- and gas-fired utility capacity were converted to coal, POM emissions from utilities would still comprise only a small fraction of the total POM emissions from combustion source categories. And, although many new utility plants will be designed to burn coal, those plants will be subject to the relatively stringent particulate emission limit [13 ng/J (0.03 lb/10^6 Btu)] specified in the 1979 NSPS applicable to coal-fired utilities. Compliance with this standard will require the use of a high-efficiency ESP or a fabric filter, both of which provide over 90 percent control of fine particles (43). As discussed above control of fine particles will result in substantial control of POM emissions.

Projections for new utility construction have generally been revised downward in recent years because conservation has reduced the need for new electrical generating capacity.

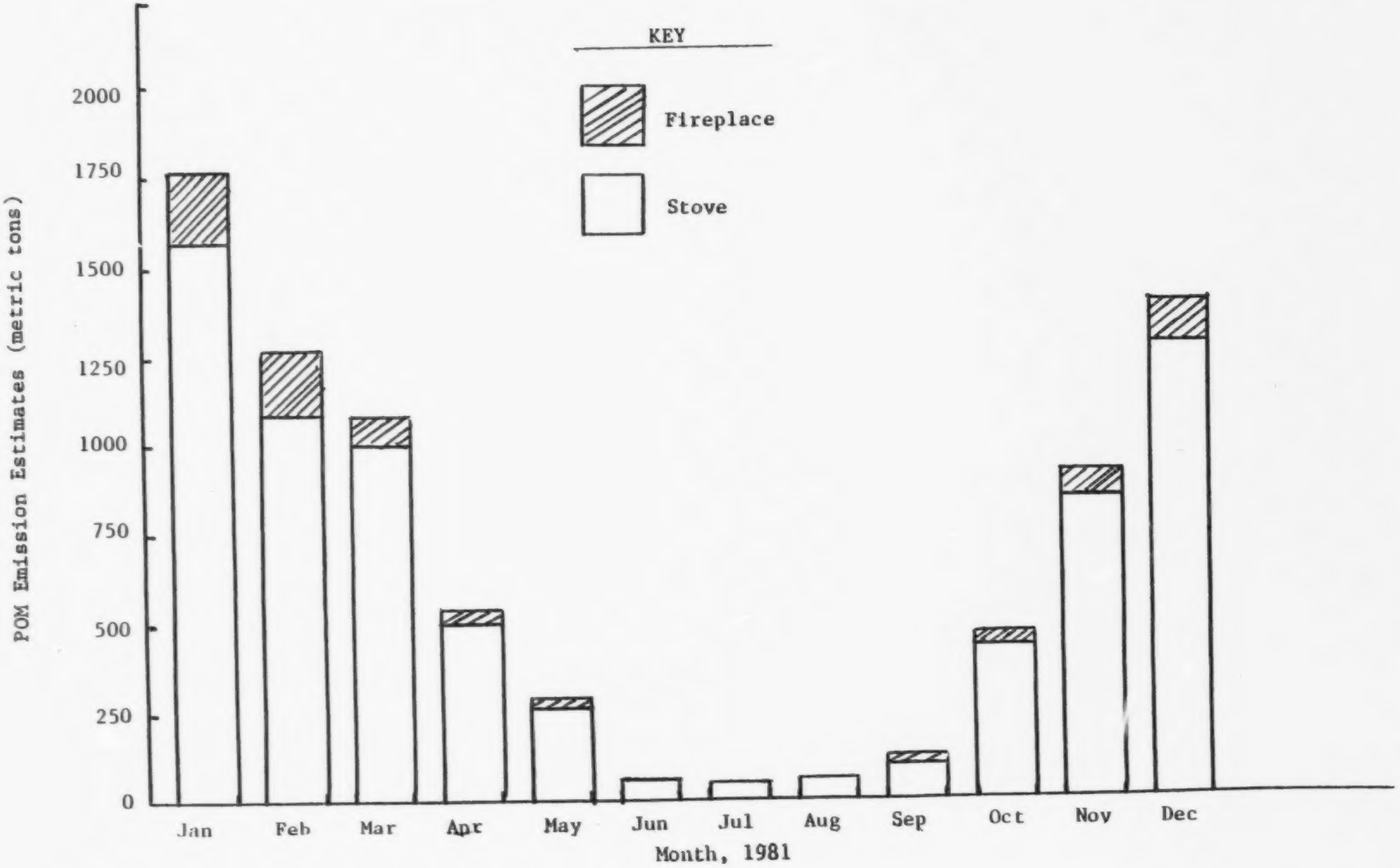


Figure 5-1. National POM Emissions from Residential Wood Combustion by Month, 1981 (37)

Industrial Combustion

Industrial growth will be accompanied by the need for additional industrial boiler capacity. The same factors influencing POM emisions from utility combustion are applicable to this category: type of fuel burned, emission controls used, and projected growth rates.

Despite possible economic advantages of using coal rather than oil or natural gas, there are several potential impediments in the current regulatory environment to a widespread or vigorous increase in industrial coal use. One recent study (44) found that about 70 percent of industrial facilities are located in non-attainment areas. The authors noted that obtaining permits for construction of new coal-fired boilers (or conversion of existing units to coal) in these areas will be difficult because of an "apparent unwillingness of existing industries" to provide emission offsets to competing firms. In addition, the concentration of industries in urban areas makes coal burning subject to strong local opposition if efficient emission controls are not applied. The capital investment required for the emission control systems, combined with the relatively large capital investment for the boiler itself, may, in many cases, make coal less economically attractive to the industrial user.

When these economic factors are combined with traditional uncertainties in securing an uninterrupted supply of coal (e.g. strikes, bad weather), there appears to be only certain cases where industrial coal use would be favored. Using specific case studies, the report cited above (44) concluded that coal use appears most economical for energy-intensive industries, such as petroleum refining and primary metals, that are located near suitable coal supplies. The study also concluded that the use of coal in large energy-intensive industries located along the Gulf Coast (e.g., chemicals and primary aluminum plants) is less likely to be cost-effective in the near term. For smaller, less energy-intensive industries, capital requirements may be unjustifiable, regardless of location.

Future fuel choice decisions for industrial boilers will be significantly affected by oil and gas prices, federal energy policies, coal transportation costs, technology developments and environmental regulations. It is difficult to assess what emission control requirements will be applicable to new industrial boilers, since the NSPS for that category has yet to be proposed. However, the NSPS will likely require a higher degree of particulate emission control than current state regulations. Also, as discussed above, local air quality considerations, especially in non-attainment areas, are likely to require the use of efficient emission controls on new boilers.

Figure 5-2 shows the growth in industrial wood consumption over the past 30 years. (The consumption values in Figure 5-2 include wood fired in process heaters, which was not included in the calculation of national POM emissions from wood combustion presented in the previous section.) Figure 5-2 shows that industrial wood consumption has been fairly steady for the last four years. The pulp and paper and lumber and wood products industries, major users of wood-fired boilers, are tied directly to the housing industry. Process technology changes, energy conservation, and a shift away from the most energy intensive products may result in some reduction in energy consumption in the pulp and paper and related industries (37). One source predicts that 1950 MW (6.65×10^9 Btu/hr) of new wood-fired boiler capacity will be installed between 1982 and 1990 (45). The added capacity is foreseen as a result of growth in the pulp and paper and lumber industries and trends in these industries toward replacement of fossil fuel-fired boilers with wood units. Replacement of older existing wood-fired boilers will also account for some of the new capacity installed.

An NSPS for wood-fired industrial boilers has not been developed. The same local air quality considerations discussed above for coal-fired boilers would apply to construction and regulation of new wood-fired units.

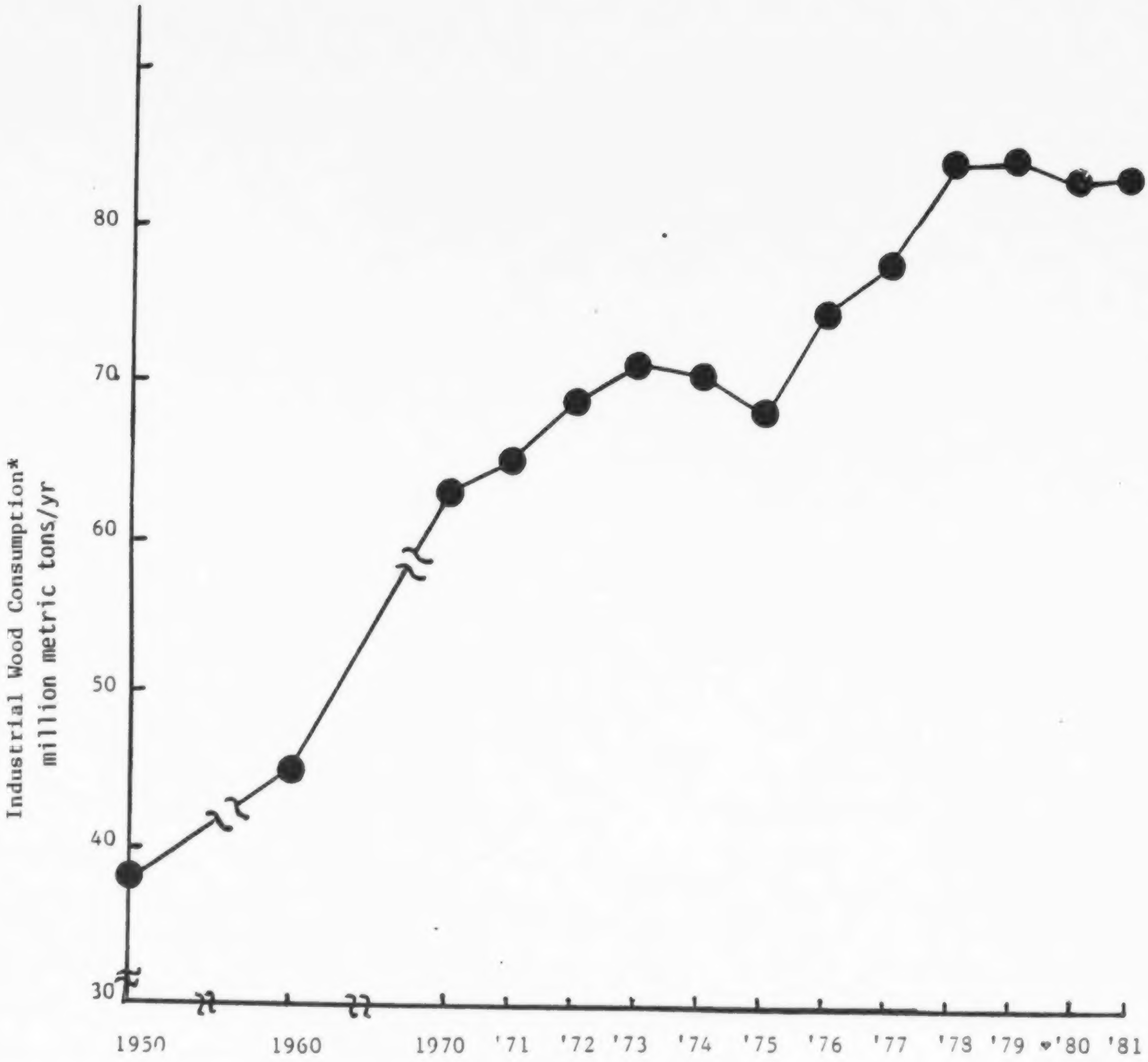


Figure 5-2. Industrial Wood Consumption Trends (37)

*Includes consumption in boilers and process heaters.

Commercial/Institutional Combustion

No quantitative data were located on the expected growth in commercial/institutional combustion. However, some qualitative assessments are possible. Continued population growth in urban areas will result in construction of new commercial and institutional boilers. Fuel choice decisions for these boilers will be driven by the same factors that affect industrial fuel choices: regional location, oil and gas prices, energy policies, coal transportation costs, technology developments, and environmental regulations. However, development of alternate energy sources, such as solar heating, and energy conservation practices may reduce the growth in this category, however.

New commercial/institutional boilers with heat input capacities of greater than 14.7 MW (50 x 10^6 Btu/hr) will likely be required to use the same particulate control systems specified for industrial boilers under the NSPS being developed (33). However, many commercial boilers are smaller than 14.7 MW and will likely be subject only to SIP emission limits. In most states, particulate emission limits are significantly less stringent for small boilers.

Residential Combustion

Because of the potential for significant POM emissions, the predicted growth of wood-fired stoves is of particular concern. Figure 5-3 shows 30-yr trends for residential wood combustion in stoves. These data support the analysis that although residential wood consumption dropped sharply in the 50's and 60's increasing oil and gas prices resulted in a significant increase in the use of wood in the residential sector during the last decade.

It seems likely, that if oil, gas, and electricity prices continue to increase, residential wood consumption will increase, especially as more efficient stoves are introduced. However, the use of alternate energy sources such as solar heating could become competitive with wood.

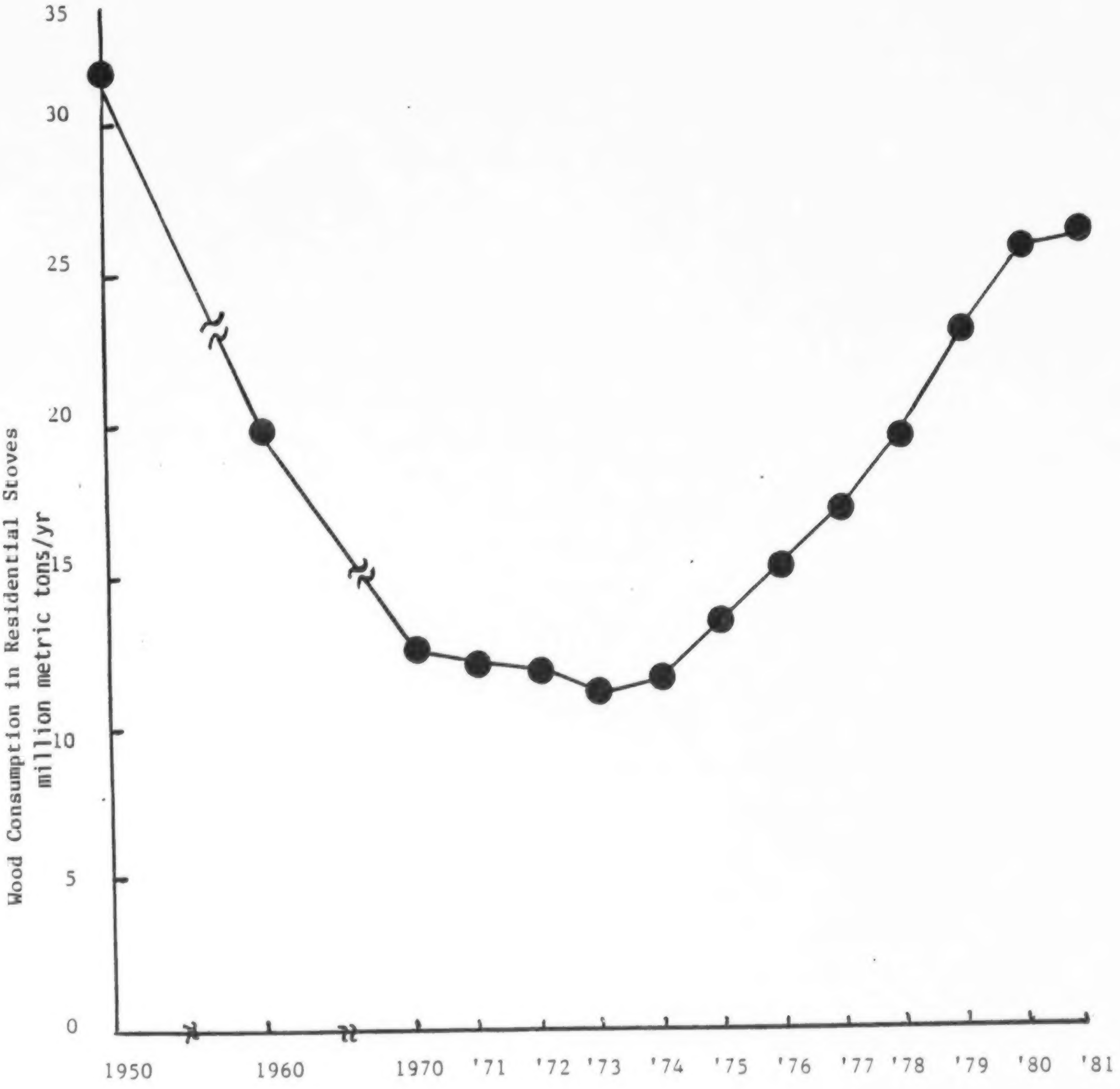


Figure 5-3. Trends in Residential Wood Consumption (Stoves) (37)

Because of the uncertainty associated with predicting residential fuel prices and fuel choice decisions it is difficult to estimate future levels of residential wood consumption. To provide an idea of the potential increase in POM from residential wood combustion in stoves, it can be assumed that the consumption levels will grow at annual rate equal to that demonstrated between 1980 and 1981 (about 1.4 percent). Assuming that no significant changes occur in control of POM from wood stoves, annual emissions by 1990 could potentially reach 8160 metric/tons/yr (assuming 0.27 gm POM emitted per kg of wood burned).

5.4 COKE PRODUCTION

This section deals with POM emissions from by-product coke production.

5.4.1 Source Category Description

5.4.1.1 Process Description*

Coke production is an integral part of iron and steel manufacturing. Coke provides the heat and carbon for the smelting and reduction reactions that occur in furnaces. About 93 percent of the coke produced is used to convert iron ore into iron. Iron foundries, nonferrous smelters, and chemicals plants account for the remainder of coke consumption.

By-product coke production is carried out in enclosed slot-type ovens. There can be 10 to 100 ovens per coke battery and there are usually several batteries located at each plant. Figure 5-4 depicts a typical plant. The major components of the by-product coke process (a batch-type process) are:

- o charging the ovens with pulverized coal that has been blended to the desired size and composition,

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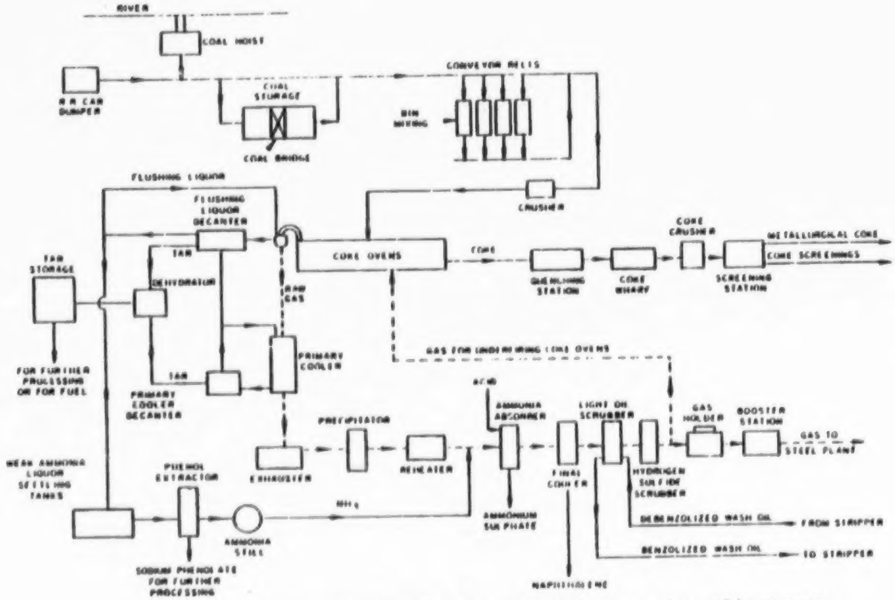
*The material presented in this subsection is summarized from References 46 and 47.



Flow sheet showing the major steps in the by-product coking process. (copyright 1971 by United States Steel Corporation)

Figure 5-4. By-Product Coking Process (46)

- coking reaction (coking time varies between 16 and 20 hours),
- pushing (after coking is complete, the coke is mechanically pushed into quench cars for transport to the next process step),
- quenching the hot coke with water, and
- recovery of by-products such as tar, ammonium sulfate, benzene, and naphthalene

With the exception of by-product recovery, existing data indicate that each of the process operations listed above is a source of POM emissions.

Fugitive emissions are associated with charging and leaks from coke oven door, lids, and offtakes. (Leaks from lids and offtakes are often grouped together under the category of topside leaks.) Battery stacks are located on the ovens to provide a natural draft for the combustion gas that is used to heat the battery. Oven gases leak through the oven walls and are emitted through these stacks. Pushing results in fugitive emissions. In the quench tower, emissions are carried up and out of the tower by the steam produced during quenching of the hot coke. Finally, although by-product recovery is a potential source of POM, very little data are available on this portion of the process.

5.4.1.2 Emission Controls/Regulations

Table 5-12 shows the emission controls applicable to by-product coke production. No quantitative date were located on the use of these systems on existing sources. However, between 80 and 90 percent of the existing capacity is subject to some type of control requirements, either under SIPs or by special consent decrees (49). The SIP and consent decree requirements vary from being relatively stringent for new and some existing sources to no control required (50).

TABLE 5-12. EMISSION CONTROLS APPLICABLE TO BY-PRODUCT COKE PLANTS (48)

Process	Type of Control[a]	Control Techniques	Estimated Control Efficiency (%)
Wet Coal Charging	Containment	Staged charging, aspiration to draw emissions into battery.	~50 to 75[b]
Door Leaks	Containment and/or Capture and Control Devices	Use and maintenance of doors designed to close tightly. Individual hoods on doors. Wet scrubbers and wet ESPs are candidate control devices.	~50 to 80[b]
Topside Leaks	Containment	Application of sealing compounds to leaks.	~35 to 50[b]
Pushing	Capture and Control Devices	Enclosures: sheds over "coke side" of battery. Wet scrubbers and wet ESPs are candidate control devices.	~50 to 90[b]
Quenching	Process Changes	Use of single or multiple baffles in the quench tower and use of only clean water for quenching. Another alternative is dry quenching, but dry quenching would require capture and control devices.	40 to 80[c]
Battery Stacks	Containment and/or Control Devices	Patching cracks in oven walls or treating exhaust gases in scrubbers, EPSs, or fabric filters.	DNA
By-Product Recovery	DNA	DNA (Likely to be various forms of containment)	DNA

[a] As characterized in Reference 48.
[b] Reference 48.
[c] Reference 55.

DNA = Data not available.

There is currently a program underway at EPA to develop a NESHAPs for coke ovens. The alternatives being considered for the NESHAPs, which would apply to both existing and new sources, range from achieving 35 to 80 percent reduction over current estimated levels of BSO emissions (51) from charging, door leaks, and topside leaks (51).

The existing and developing regulations for coke ovens are generally in the form of work practice standards because of the extreme difficulties associated with measuring mass emissions from these sources. Typical regulations for charging specify the amount of time that visible emissions can occur during charging. Other regulations specify the allowable percent of leaking doors (PLD), of leaking lids (PLL), and of leaking offtakes (PLO) (50). Regulations for quench towers do, in some cases, specify mass emission levels, but many just restrict the quality of water that can be used in quenching (52).

The Occupational Health and Safety Administration (OSHA) has developed and is enforcing regulations related to worker safety. These regulations dictate certain work practice procedures (50).

5.4.1.3 Source Locations

By-product coke plants are located in 18 states. Most of the plants are located near steel plants and coal supply points. Forty-seven of the estimated 60 plants are owned by or affiliated with iron and steel firms (53).

In 1976, 57 percent of total U.S. coke was produced in Pennsylvania. Ohio and Indiana were the next largest producers. Other states with significant coke production capacity include Alabama, West Virginia, Maryland, New York, and Michigan. The relative amount of coke produced in various states has been fairly stable (53).

5.4.2 Emission Factors

Most of the emission data reported for coke ovens are based on emissions of BaP or benzene soluble organics (BSO). Very little total POM data are available. Table 5-13 summarizes emission factor data from references reviewed in this study. Total POM data were located only for door leaks (uncontrolled and controlled) and quenching operations. Comparison of BSO data available for the various process operations shows that charging, door leaks, and quenching (with contaminated water) are the largest potential emission sources.

Tables 5-14 through 5-17 show the type of POM compounds included in the total POM data reported in Table 5-13.

5.4.3 National Emission Estimates

Development of national total POM emission estimates for coke production is difficult and uncertain due to the lack of total POM data and the wide variability of the limited data published. However, a very rough estimate of the lower end of the range of national emissions can be developed by assuming that POM emissions are at least equal to those from door leaks and quenching.

An emission factor of 4 gm/metric ton of coal charged is representative of door leaks without an add-on control device. For quenching, an emission factor of 2 gm/metric ton of coal charged was assumed. Thus, an estimated total POM emission factor of 6 gm/metric ton of coal was used to calculate national emissions. This factor is based on the use of relatively clean water for quenching. Most states limit particulate emissions from quenching to 1.24 kg/metric ton of coal charged or less (54). However, compliance with such limits is based on the use of clean water since emissions from these sources are very difficult to measure accurately (55).

TABLE 5-13. EMISSION FACTOR DATA FOR COKE PRODUCTION

Process	Emission Factors (gm POM/metric ton of coal charged) POM	BaP	BSO	Comments	Reference
Charging	a		50 to 550	"Poorly-controlled"	58
Door Leaks	4.3[b]	0.002-1.4	4.2 to 260	c	59
	7×10^{-5}[d]		0.25	Controlled with wet ESP	60
Topside Leaks			0.004 to 0.05	"Poorly-controlled"	58
Pushing			8 to 17	c	59
Quenching	0.002-0.009[e]	0.0005	11 to 2800	c	59
	1.85[f]			Clean water for quench	61
	613[f]			Contaminated water for quench	61
Battery Stacks		0.002 to 0.02	1.6	c	59

[a] Blanks indicate that no emission factor data were located in references reviewed.

[b] Includes 13 POM compounds as shown in Table 5-14.

[c] Original reference for these data is given as: Trenholm, Andrew R. and Lee L. Beck. Assessment of Hazardous Organic Emissions from Slot-Type Coke Oven Batteries, Internal EPA Report, Durham, NC, March 16, 1978.

[d] Includes POM compounds shown in Table 5-15.

[e] Includes 10 POM compounds shown in Table 5-16.

[f] Average of tests for green and non-green coke. Sampling conducted with a modified EPA Method 5 apparatus; samples analyzed by GC/MS for 33 PAH compounds and 18 polar POM compounds. Table 5-17 shows compounds found in relatively higher amounts. Reference 55 presents data on all POM sampled for in the tests.

TABLE 5-14. POM COMPOUNDS MEASURED IN UNCONTROLLED COKE OVEN DOOR LEAK SAMPLES (59)

Benzo(a)phenanthrene
Benzo(e)pyrene
Benzofluoranthenes
Benzo(k)fluoranthene
Chrysene
Dibenzanthracenes
Dibenzpyrene
Dimethylbenz(a)anthracene
Fluoranthene
Indeno(1,2,3-c,d)pyrene
Naphthalene
Pyrene
Benzo(a)pyrene

TABLE 5-15. POM COMPOUNDS MEASURED IN CONTROLLED DOOR LEAK SAMPLES (60)

Naphthalene
Fluoranthene
Pyrene
Benz(c)phenanthrene
Chrysene
Benz(a)anthracene
7,12-Dimethylbenz(a)anthracene
Benzofluoranthenes
Benzo(a)pyrene
Benzo(e)pyrene
Cholanthrene
Indeno(1,2,3-c,d)pyrene
Dibenz(a,h)anthracene
Dibenzacridines
Dibenz(c,g)carbazole
Dibenzpyrenes
3-Methyl cholanthrene

TABLE 5-16. POM COMPOUNDS IDENTIFIED IN COKE QUENCH TOWER EMISSIONS - INTERNAL EPA DATA (59)

Anthracene and phenanthrene
Methyl anthracenes
Fluoranthene
Pyrene
Methyl pyrene and fluoranthene
Benzo(c)phenanthrene
Chrysene and benz(a)anthracene
Methyl chyrsenes
Dimethylbenz(a)anthracene
Benzo(a)pyrene

TABLE 5-17. SELECTED POM COMPOUNDS IN COKE QUENCH TOWER SAMPLES - PUBLISHED DATA (61)

Benzo(a)pyrene

3-Methyl cholanthrene

7,12-Dimethylbenz(a)anthracene

Dibenz(a,h)anthracene

Dibenzo(a,h)pyrene

Dibenzo(a,i)pyrene

Benz(a)anthracenes

Pyridine

Indeno(1,2,3-c,d)pyrene

Phenanthrene

Phenol

Cresol

Quinoline

The emission factor was then multiplied by the 1980 coke production level of 41.8 million metric tons (56) and a typical yield of coke from coal of 69 percent (57) to yield a national estimate:

$$\left(\frac{6\text{gm POM}}{\text{metric ton coal charged}}\right)\left(\frac{\text{ton coal charged}}{0.69\text{ ton coke}}\right)\left(\frac{41.8 \times 10^{6}\text{ metric tons coke}}{\text{yr}}\right)\left(\frac{\text{metric ton}}{10^{6}\text{ gm}}\right) = 363\text{ metric tons POM/yr (400 tons/yr)}$$

This estimate is likely to represent the low end of the estimated range of national POM emissions from by-product coke production because only door leaks and quenching tower emissions are included and it was assumed that clean water was used in quenching.

5.4.4 Trends Influencing POM Emissions

The two major factors that will influence POM emissions from by-product coke production are:

- proposal/promulgation of coke oven NESHAPs and
- coke production levels.

Published alternatives being considered for the coke oven NESHAPs are expected to require between 35 to 80 percent reduction of BSO emissions over current levels, depending on the emissions source and the alternative selected (51). These standards would apply to both new and existing coke ovens.

Production levels are related to the iron and steel industry which, as discussed in Section 5.5.4 is expected to experience only moderate growth in the next few years (1 to 3 percent annually).

5.5 IRON AND STEEL PROCESSES

This section describes, in general, some iron and steel processes that potentially emit POM. The discussion focuses on iron and steel sintering and ferroalloy production, two categories for which at least some information on POM emissions was located. Because there were insufficient published total POM emission data, the development of national emission estimates for iron and steel sintering was not feasible.

5.5.1 Source Category Description

5.5.1.1 Process Description

Several iron and steel processes may potentially emit POM. Specific information was located for iron and steel sintering and ferroalloy production. The POM emissions from non-ferrous alloy production and other metals manufacturing may be similar to those described for ferroalloy production.

Sintering--Sintering is the process by which pulverized ore is agglomerated before it is used in a blast furnace. A traveling grate moves the ore over a series of wind boxes where air is pulled through the grate and the ore is ignited with a burner (62). The ore contains coke and oil scrap and POM compounds are generated from the burning of this material. Also, coke and scrap particles with absorbed POM can escape at several points in the process (62). Much of the POM may be emitted as vapor at sintering process temperatures (62).

Ferroalloy Production--In production of ferroalloys, reducing materials such as coal or coke and ores are charged to a furnace on a continuous or cyclic basis. Furnace operation is continuous. In the most commonly used process (electric arc furnaces) reactions occur in the zones surrounding large electrodes. Burning of the coal or coke generates carbon monoxide, particulate matter, vaporous metallic compounds, and POM (63) which are emitted through the furnace exhaust. Electric arc furnaces which can be open, closed, or semi-sealed are also used in ferrous foundries, specialty and alloy steel production, and nonferrous alloy production.

5.5.1.2 Emission Controls/Regulations

Sintering--In 1976, two-thirds of the existing iron and steel sintering process factilities had no emission controls (62). Possible control technologies include ESPs, fabric filters, and wet scrubber, all of which would capture significant amounts of POM. Wet scrubbers would likely be the most efficient in reducing the total POM because vapor phase compounds would be condensed in the scrubber. No federal NSPS exists for iron and steel sintering.

Ferroalloy Production--Exhaust gases from the electric arc furnaces are typically vented to wet scrubbers or fabric filters, both of which should provide significant POM control. Fabric filters are used at 26 of the 31 ferroalloy plants in the United States (63). A 1974 NSPS limits particulate emissions, opacity, and carbon monoxide emissions from "new" electric arc furnaces producing silicon-, manganese-, and chrome-based alloys. Federal NSPS also exist for electric arc furnaces in iron and steel producion facilities and non-ferrous alloy manufacture and an NSPS is being developed for electric arc furnaces used in ferrous foundries (64). Most states also have particulate emissions regulations applicable to existing metal production facilities that have required the use of emission control equipment.

5.5.1.3 Source Locations

Sintering--Sintering occurs in conjunction with operation of large blast furnaces. These plants are concentrated in Ohio, Pennsylvania, and Indiana (62).

Ferroalloy Production--Production of ferroalloys is concentrated in the same states as sintering (Ohio, Pennsylvania, and Indiana) as well as in West Virginia, Alabama, Kentucky, and Tennessee. There are also large facilities located in Colorado and California (65).

5.5.2 Emission Factors

Sintering--Only BaP data were available for the sintering process (62). The BaP emission estimates ranged from 0.66 to 1.1 gm per metric ton of sinter feed.

Ferroalloy Production--POM emission data were collected from a semi-sealed and a closed electric arc furnace in a recent study supporting review of the ferroalloy NSPS (66). POM emissions from the semi-sealed furnace (producing 50 percent FeSi) were 91.0 gm/Mw-h. This facility was controlled with a low energy wet scrubber followed by a flare. Emissions were measured before the flare. Tests on the closed furnace (producing SiMn) showed controlled POM emissions of 1.0 gm/Mw-h. The closed furnace was controlled by a high pressure drop wet scrubber. Emissions from the closed furnace measured before the scrubber were 156 gm/Mw-h when the furnace was producing FeMn. Table 5-18 shows the compounds detected in the furnace exhausts sampled.

No emission factor data were presented for open furnaces, which are used in the large majority of ferroalloy plants (65). However, one report reviewed did present an annual nationwide POM estimate for open furnaces (see Section 5.5.3).

5.5.3 National Emission Estimates

As stated above, no useful total POM emission factors were available for the iron and steel sintering. Therefore, development of a national POM emission estimates for this category was not feasible.

Reference 67 presented total uncontrolled POM emission estimates for electric submerged-arc furnaces used in ferroalloy production:

TABLE 5-18. POM EMISSIONS IN FERROALLOY ELECTRIC ARC FURNACE EXHAUST (66)

	Semisealed Furnace Test C-2, during 50% FeSi Production		Closed Furnace Test D-2, during SiMn Production		Closed Furnace Test D-1, during FeMn Production[a]	
	mg/Nm^3	g/MW-h	mg/Nm^3	g/MW-h	mg/Nm^3	g/MW-h
Fluorene	75.0	45.9	1.5	0.36	16.0	4.0
Carbazole	b				9.6	2.4
Anthracene	18.3	11.2	2.1	0.51	220.0	54.9
Phenanthrene	18.3	11.2				
Cyclopenta(def)phenanthrene	10.7	6.5				
Methylanthracenes	1.5	0.92	0.070	0.017	24.0	6.0
Fluoranthene	27.4	16.7	0.24	0.058	220.0	54.9
Pyrene	28.5	17.4	0.22	0.053	2.3	0.57
Methylpyrene	0.07	0.04	0.005	0.0012	14.0	3.5
Benzo(ghi)fluoranthene	8.9	5.4				
Benzo(a) and benzo(b)fluorene	1.24	0.75				
Chrysene	8.1	4.9	0.016	0.0039	49.0	12.0
Benz(a)anthracene	10.5	6.4				
Methylchrysenes					5.2	1.3
7,12-dimethylbenz(a)anthracene					0.58	0.14
Benzo(e)pyrene	0.81	0.49			51.0	13.0
Benzofluoranthene						
Benzo(j)fluoranthene	3.5	2.1				
Benzo(k)fluoranthene	0.16	0.10				
Benzo(e)acephenanthylene	3.5	2.1				
Perylene	0.43	0.26			3.1	0.77
Benzo(a)pyrene	1.64	1.00				
Methylbenzopyrenes					1.2	0.30
3-methylcholanthrene					0.39	0.10
Indeno(1,2,3-c,d)pyrene	1.10	0.67			6.0	1.5
Benzo(ghi)perylene	3.2	1.9			1.4	0.35
Anthanthrene	0.83	0.51				
Dibenzo(a,h)anthracene					0.90	0.22
Dibenzo(c,g)carbazole					0.079	0.020
Dibenzo(ai+ah)pyrenes					0.54	0.13
Coronene	1.0	0.61			0.51	0.13
TOTAL		91.0		1.0		156.0

[a] Before scrubber.

[b] Blanks indicate compound not detected.

Furnace Type	Estimated POM Emissions (metric tons/yr)
Covered furnaces	209 to 1879
Open furnaces	135 to 1211

These calculations were based on actual emission factor data measured upstream of emission control devices such as scrubbers and fabric filters. However, it is likely that such control devices would substantially reduce the amount of POM emitted to the atmosphere (67). Reported "organic" collection efficiencies of the scrubbers on five furnaces tested ranged from 16 to 97 percent (67). As noted elsewhere in this report, fabric filters are expected to achieve significant reductions in POM since the fine particulate onto which POM is typically adsorbed is efficiently collected by fabric filters.

POM emissions were reportedly significantly higher for closed furnaces than for open furnaces on the basis of POM emitted (uncontrolled) per unit of furnace capacity.

5.5.4 Trends Influencing POM Emissions

Only low to moderate growth (1 to 3 percent annually) is foreseen for the iron and steel industry (68). Increased metals imports, high capital outlays required for modernization expenditures to meet environmental regulations, and the slow growth of steel-intensive industries are the major factors contributing to sluggish growth in this industry.

Any new capacity will be subject to the NSPS which generally requires the use of fabric filters or high pressure drop wet scrubbers.

5.6 ASPHALT PRODUCTION - PAVING AND ROOFING

This section describes two asphalt-related sources of POM emissions: manufacture of asphalt hot mix used in paving and air blowing of asphalt and subsequent saturation of felt for asphalt roofing products.

5.6.1 Source Category Description

5.6.1.1 Process Descriptions

Asphalt Hot Mix--Production of asphalt hot mix involves mixing asphalt aggregates with hot liquid asphalt cement in a batch or continous process. A large percentage of the hot mix is produced in existing plants using the batch process shown in Figure 5-5a (71). The drum-mix process, in which wet aggregate is dried and mixed with hot liquid asphalt cement as it is simultaneously dried in a rotary dryer, has been used in most new plant designs (132). This process is shown in Figure 5-5b. Drum-mix plants are also being used to recycle salvaged asphalt pavement. Most asphalt mix plants are relatively small: the average production rate is 160 metric tons/hr (176 tons/hr) (69). POM compounds are emitted from combustion of gas or oil in the direct-feed rotary dryer and from the mixer. Because the drum-mix process is based on a parallel flow design (i.e., hot gases and aggregate flow through the dryer in the same direction), particulate emissions from this process are less than from a conventional process. However, because the asphalt is heated to a higher temperature for a longer time, the drum-mix process may result in greater POM emissions.

Fugitive emissions of POM may result from asphalt loading and handling. As with most batch processes, emissions are highly variable.

In recent years, virtually all new plants are drum-mix operations in which mixing and drying of the aggregates occurs within the same vessel (132).

Asphalt Roofing Products--The two major steps in the production of asphalt-based roofing products are air blowing of the asphalt and saturating a felt with the air blown material.

Although the processes are not always carried out at the same plant, air blowing is an integral part of felt production. Air blowing involves accomplishing oxidation by bubbling air through liquid asphalt at 220 to 260°C (428

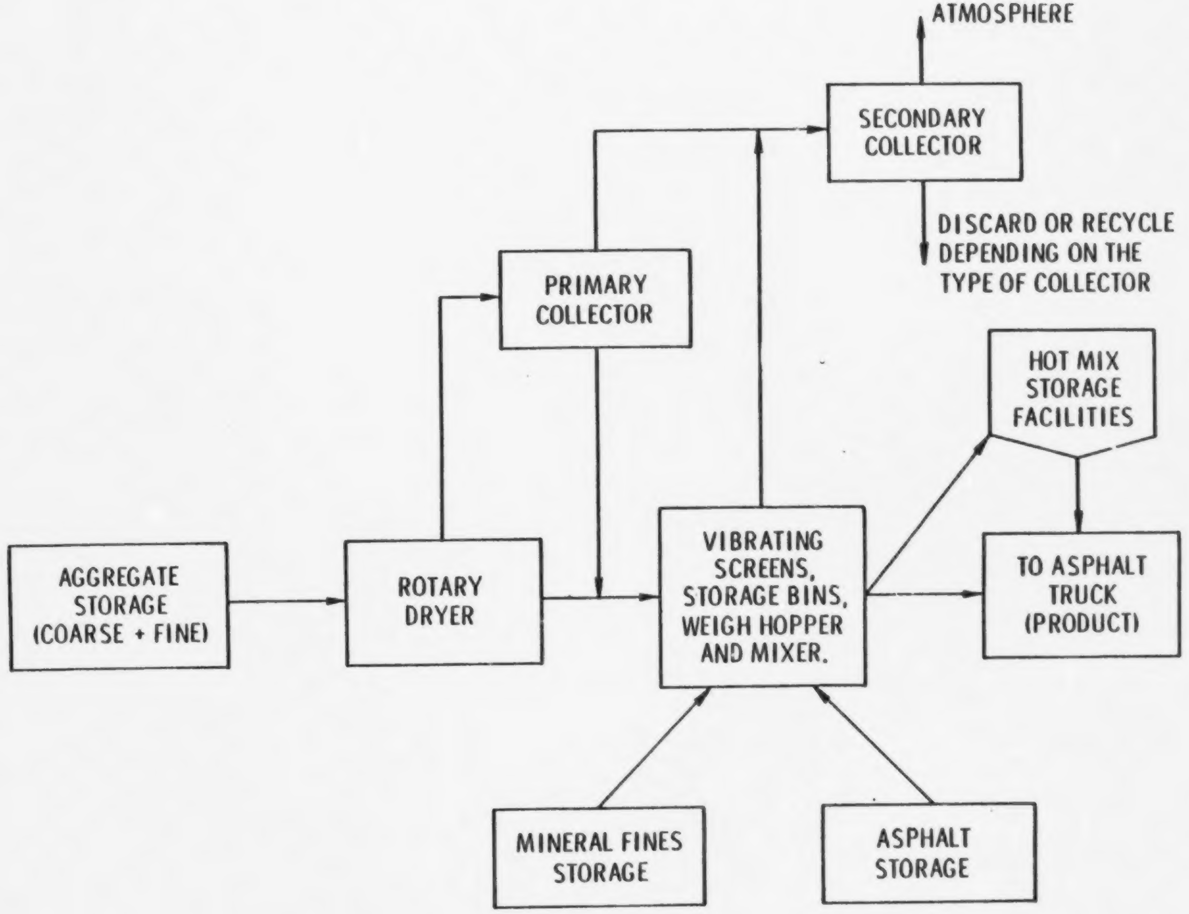

ATMOSPHERE
SECONDARY COLLECTOR
DISCARD OR RECYCLE DEPENDING ON THE TYPE OF COLLECTOR
PRIMARY COLLECTOR
HOT MIX STORAGE FACILITIES
AGGREGATE STORAGE (COARSE + FINE)
ROTARY DRYER
VIBRATING SCREENS, STORAGE BINS, WEIGH HOPPER AND MIXER.
TO ASPHALT TRUCK (PRODUCT)
MINERAL FINES STORAGE
ASPHALT STORAGE

Figure 5-5a. Block Flow Diagram of Batch Hot Mix Production (69)

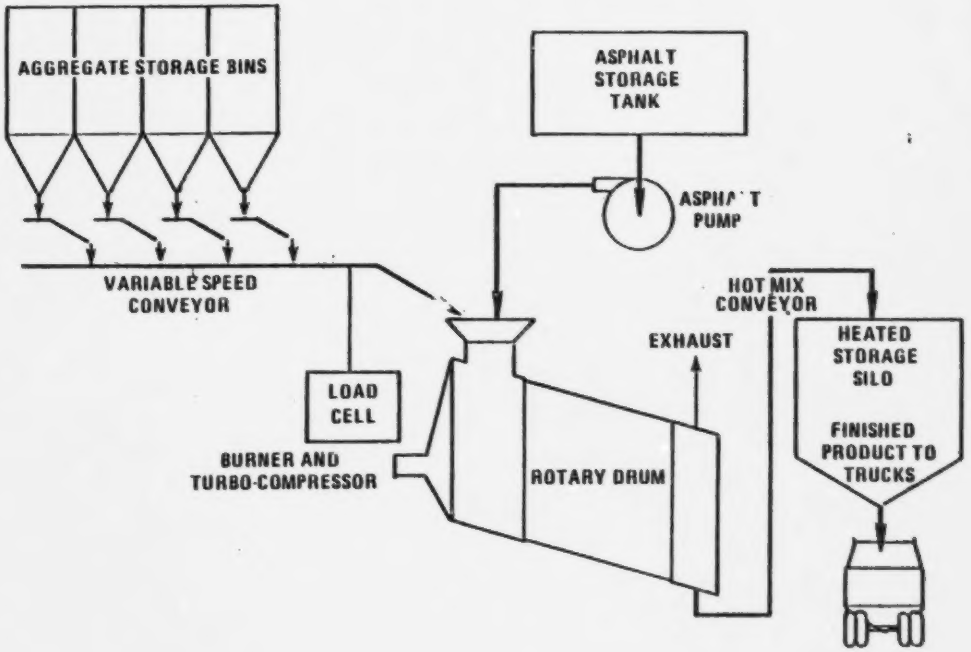


Figure 5-5b. Block Flow Diagram of Shearer Type Drum-Mix Hot Asphalt Plant (32)

to 500°F) for 1 to 4 hours. Emissions are highly variable due to the cyclic nature of the process (70).

Saturating the felt involves dipping it in airblown asphalt, spraying it with the asphalt, or, in some cases, a combination of both techniques. The final felt product, with controlled thickness coating of asphalt, is made into rolls or shingles (70).

5.6.1.2 Emission Controls/Regulations

Asphalt Hot Mix--Wet scrubbers and fabric filters are typically used at asphalt hot mix plants (74). No data were located on the effect of these devices on POM emissions from the hot mix process. However, it can be expected that both types of control equipment will provide a significant degree of control of process emissions of POM because of their relatively high fine particle collection efficiencies. Fugitive emissions from hot mix production, on the other hand, are largely uncontrolled.

An NSPS for asphalt hot mix production was proposed in June of 1973. The NSPS limits particulate matter emissions and the opacity of outlet stack gases from plants (75). The NSPS applies to facilities constructed after June 1973. The NSPS is currently being reviewed by EPA (132).

Asphalt Roofing Products--Typically, controls for air blowing of asphalt consist of a primary cyclone (to catch larger particulate matter) followed by a fume incinerator (70). No data were located regarding the effect of such a control system on POM emissions.

Saturating operations are generally enclosed by fume hoods which are vented to emission control devices. The control devices used on various plants include low voltage ESPs, afterburners, and high energy air filter (HEAF) systems. Limited data showed HEAF systems reduced total POM by about 70 percent, while direct-fired afterburners had no effect on POM (70).

An NSPS limits particulate emissions and opacity from saturators and blowing operations used in manufacturing roofing products and constructed after November 1980 (75). ESPs, high velocity air filters and afterburners are expected to be used to meet this NSPS (75).

5.6.1.3 Source Locations

Asphalt Hot Mix--About 20 percent of the 4300 operating asphalt hot mix plants are mobile (71). Most permanently installed plants are located in urban areas. As of 1974, states with 5 percent or more of the national asphalt hot mix capacity were California, Illinois, New York, Pennsylvania, and Ohio (72).

Asphalt Roofing Products--The majority of asphalt roofing product plants are also located in urban areas. Six large plants (out of an estimated 200 total plants) were reported to account for 20 percent of production in 1973 (73). Four states were reported to have 15 or more roofing product plants: California, Illinois, Texas, and New Jersey (73).

5.6.2. Emission Factors

The limited emission factor data located for these categories are presented below. In both cases, published data were limited to one or two emission tests conducted at what were considered to be representative facilities.

Asphalt Hot Mix--Controlled emissions from the stack exhaust and mixer at a batch production facility were reported to be 13.0 mg per metric ton of hot mix produced (76). The plant was equipped with a primary cyclone followed by a wet scrubber. No information was provided on the emission test method used. Table 5-19 shows the POM compounds identified in the stack exhaust. Reported analytical errors ranged from 6 to 144 percent for the different compounds. No fugitive emission factor data were located, nor were data

TABLE 5-19. POM COMPOUNDS IDENTIFIED IN STACK EXHAUST EMISSIONS FROM A CONTROLLED ASPHALT HOT MIX PLANT (76)

Dibenzothiophene
Anthracene/phenanthrene
Methylanthracenes and phenanthrenes
9-Methylanthracene
Fluoranthene
Pyrene
Benz(c)phenanthrene
Chrysene/benz(a)anthracene
7,12-Dimethylbenz(a)anthracene
3,4-Benzofluoranthene
Benzo(a)pyrene
Benzo(e)pyrene
Perylene
3-Methylcholanthrene
Dibenz(a,h)anthracene
Indeno(1,2,3-c,d)pyrene
7H-Dibenzo(c,g)carbazole
Dibenzo(a,h and a,i)pyrene

available for the newer drum-mix facilities. [In the course of its NSPS review, EPA plans to conduct emission tests at drum-mix facilities (132).]

Asphalt Roofing Products--Controlled POM emissions from air blowing and saturator operations were reported as (77):

Air blowing:	2.1 mg POM/metric ton felt produced
Saturators:	4.3 mg POM/metric ton felt produced

These data represent the average emissions from two representative facilities. The air blowing operations tested were equipped with fume incinerators. At one air blowing operation, POM compounds were reduced by about 80 percent across the fume incinerator, but at the other facility POM increased by a factor of two across the incinerator (77).

One of the saturators tested was equipped with a HEAF system which showed 70 percent reduction of POM. The other saturator tested was equipped with a fume incinerator which reportedly had no effect on POM emissions (77).

The data were collected using a Method 5 sampling train modified by placing the filter after a series of impingers. Table 5-20 shows the POM compounds identified in samples from the air blowing operations tested.

5.6.3 National Emission Estimates

The emission estimates for these categories were calculated by multiplying estimated 1980 national production levels by the emission factors presented above.

Asphalt Hot Mix--Annual production of hot mix in 1980 was reported to be 22.1 × 10^6 metric tons (24.3 × 10^6 tons) (78). This figure agrees relatively well with a 1976 production level of 20 × 10^6 metric tons used in an earlier study (79), but is an order of magnitude lower than a 1975 estimated production level of 300 × 10^6 metric tons attributed to the National

TABLE 5-20. POM COMPOUNDS IDENTIFIED IN SAMPLES FROM ASPHALT AIR BLOWING AND FELT SATURATION (77)[a]

Benz(c)phenanthrene
7,12-Dimethyl(a)anthracene
Benzo(a)pyrene
Benzo(e)pyrene
3-Methylcholanthrene
Dibenz(a,h)pyrene
Dibenz(a,i)pyrene

[a] Sample extracted with methylene chloride and analyzed by GC/MS.

Asphalt Pavement Association (80). Since the 1980 estimate was more recent and since the original reference for the higher estimate was not readily available, the 1980 estimate was used in calculating national emissions:

$$\left(\frac{22.1 \times 10^{6} \text{ metric tons hot mix}}{\text{yr}}\right)\left(\frac{13.0 \times 10^{-3} \text{ gm POM}}{\text{metric ton hot mix}}\right)\left(\frac{\text{metric ton}}{10^{6} \text{ gm}}\right)$$

$$= 0.29 \text{ metric ton/yr } (0.32 \text{ ton/yr})$$

These estimates are based on the emission factors for batch plants and do not reflect emissions from newer drum-mix plants.

Asphalt Roofing Products--In 1980, an estimated 5.3×10^{6} metric tons (5.8×10^{6} tons) of asphalt roofing products were manufactured (78). Based on the controlled emission estimates presented above national POM emissions were calculated as follows:

$$\text{Air Blowing: } \left(\frac{5.3 \times 10^{6} \text{ metric tons felt}}{\text{yr}}\right)\left(\frac{2.1 \times 10^{-3} \text{ gm POM}}{\text{metric ton felt}}\right)\left(\frac{\text{metric ton}}{10^{6} \text{ gm}}\right)$$

$$= 0.011 \text{ metric ton/yr } (0.025 \text{ ton/yr})$$

$$\text{Saturators: } \left(\frac{5.3 \times 10^{6} \text{ metric tons felt}}{\text{yr}}\right)\left(\frac{4.3 \times 10^{-3} \text{ gm POM}}{\text{metric ton felt}}\right)\left(\frac{\text{metric ton}}{10^{6} \text{ gm}}\right)$$

$$= 0.023 \text{ metric ton/yr } (0.012 \text{ ton/yr})$$

$$\text{Total} = 0.011 + 0.023 = 0.034 \text{ metric ton/yr } (0.037 \text{ ton/yr})$$

5.6.4 Trends Influencing POM Emissions

Asphalt Hot Mix--Asphalt hot mix production levels are related directly to the paving industry. Production levels are likely to remain relatively steady (79). New or modified plants will be covered by the existing NSPS which requires particulate emission control. Also, as mentioned above, newer facilities are likely to be drum-mix designs.

Asphalt Roofing Products--Production levels of roofing materials are dependent on the housing industry and there is also a large replacement market for these products. The 1980 U.S. Industrial Outlook (81) predicts a 2 percent growth in new construction through 1984, although the growth in this industry is highly dependent on the general state of the economy and on mortgage loan interest rates. No information was located regarding the capability of existing roofing materials production facilities to keep pace with the anticipated housing industry growth. New or modified plants will be subject to the NSPS for this category.

5.7 CATALYTIC CRACKING IN PETROLEUM PRODUCTION

This section deals with POM emissions from catalytic cracking as used in petroleum refining. Catalytic cracking is used to upgrade heavy petroleum fractions to produce high octane gasoline and distillate fuels.

5.7.1 Source Category Description

5.7.1.1 Process Descriptions

There are three basic types of catalytic cracking techniques currently used in the petroleum industry:

- fluidized catalytic cracking,
- thermofor catalytic cracking, and
- houdriflow catalytic cracking.

Fluidized catalytic cracking accounted for about 94 percent of the total refinery catalytic cracking in 1977 (82). The basic process involves heating a mixture of gas and oil to about 480°C over a silica alumina catalyst and then fractionating the mixture (82). The spent catalyst is regenerated in a kiln by burning off the coke that has coated the catalyst particles during cracking. The regeneration process in carried out about 540°C. Venting of the exhaust gases from the regeneration kiln is a potential source of POM emissions.

5.7.1.2 Emission Controls/Regulations

In many cases, exhaust gases from the regenerator are vented directly to a carbon monoxide (CO) waste heat boiler to recover the useful energy in the gases. CO boilers which are fired with auxiliary fuel or contain a catalyst have been reported to be 99 percent efficient in reducing PAH emissions (82). Direct-fired afterburners (plume burners) are reportedly not efficient controls for POM.

Catalytic cracking units constructed after June 1973 are subject to an NSPS that limits CO and particulate matter emission limits (83). The NSPS generally requires the use of a CO waste heat boiler and an ESP. State requirements applicable to new and existing catalytic cracking units also generally require some degree of particulate matter and CO control (84).

5.7.1.3 Source Locations

Refining capacity is centered in Texas, Louisiana, and California, but most states have at least one refinery (82).

5.7.2 Emission Factors

The most representative POM emission factor would appear to be one that represents the use of a CO waste heat boiler. A weighted average of the controlled emission factor data for the three types of catalytic cracking techniques was reported to be 930 μg POM per cubic meter of oil cracked (intermediate value in Reference 85). No information was provided regarding the emission test method or the POM compounds included in the sample.

5.7.3 National Emission Estimates

National POM emission estimates for catalytic cracking were derived by multiplying the emission factor given above by the reported quantity of oil subject to catalytic cracking in 1980.

The Oil and Gas Journal (86) reports that as of January 1981, U.S. catalytic cracking levels totaled 1,017,891 m^3/stream-day (6,401,833 bbl/stream day). This figure includes fresh and recycle streams. A stream day is defined as operation at full capacity for short periods. Catalytic cracking units generally operate at stream-day capacity about 90 percent of the time (86).

Based on this information, national POM emissions from catalytic cracking were estimated as follows:

$$\left(\frac{1{,}017{,}891\ \text{m}^3\ \text{cracked}}{\text{stream day}}\right)\left(\frac{.9\ \text{stream-day}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{yr}}\right)\left(\frac{930\times 10^{-6}\ \text{gm}}{\text{m}^3\ \text{oil cracked}}\right)\left(\frac{\text{metric ton}}{10^6\ \text{gm}}\right)$$

= 0.31 metric tons/yr (0.34 tons/yr)

5.7.4 Trends Influencing POM Emissions

Two factors will influence future POM emissions from catalytic cracking: oil production levels subject to cracking and recent technology developments in the cracking process itself.

Estimates of oil production levels fluctuate widely with changes in the U.S. and world economic situations, but many forecasters predict a drop in motor gasoline and distillate fuel production as a result of conservation induced by price increases, more fuel efficient cars, and a switch from distillate oil to natural gas for home heating. The Oil and Gas Journal predicted a 2 to 3 percent drop in the amount of oil subject to cracking between 1981 and 1982 (87).

More complete combustion of CO to CO_2 in the catalytic cracking process could lead to reduced POM emissions. Recent developments in this regard include the UOP hot regeneration and the Amoco Ultracat process. The relatively higher temperature for regeneration used in the UOP process improves combustion efficiency and thus could reduce POM emissions. However, the high temperatures require special materials of construction making the UOP process more suitable for new units than retrofits. The Amoco process, however, is based on improving the catalytic reactor efficiency, allowing more complete combustion to occur in the regenerator without having to operate at high temperatures (88). Thus, the technology similar to the Amoco process may be suitable for retrofit to existing units.

5.8 COMBUSTION OF MUNICIPAL, INDUSTRIAL, AND COMMERCIAL WASTES

Combustion of waste can be carried out in boilers or incinerators. Waste fuel-fired boilers recover the heat from combustion to generate steam (or, in rare cases, electricity). The primary purposes of incinerators, on the other hand, are to:

- reduce the volume of waste to be disposed of,
- reduce the toxicity of waste, or
- recover valuable resources from the waste.

Although POM emission data were located only for municipal solid waste (MSW) and commercial incinerators, several other categories are discussed below because of their similar potential for POM emissions. The categories discussed here include:

- municipal solid waste combustion (incinerators and boilers),
- industrial solid and liquid waste combustion (incinerators and boilers), and
- commercial solid waste combustion.

Hazardous waste incinerators were not reviewed in this study because of their extensive coverage under the current RCRA programs (89).

5.8.1 Source Category Description

5.8.1.1 Process Descriptions

POM emissions from waste combustion will be a function of waste composition and incinerator or boiler design and operation.

Municipal Waste Combustion--Municipal waste is generally a heterogenous mixture of wood, paper, metal, glass, and refuse. However, municipal waste can contain industrial wastes, combustion of which may result in relatively higher POM emissions (90). One source (91) estimates that in 1980 municipal solid waste contained 5 percent plastics by weight, 20 percent of which was polyvinyl chloride (PVC). Combustion of plastics may potentially increase POM emissions. Increasing utilization of plastic products would result in even higher concentrations. Another factor that may result in relatively higher POM emissions from municipal waste combustion is the expected higher percentages of organic matter, such as leaves and tree clippings, that is likely to be present during the Fall.

There are several types of municipal incinerators (90). The waste can be combusted on a moving belt, in drum-type rolling chambers, or on various types of grates. Waste can be fed continuously, as is the case for all larger, modern facilities, or it can be fed in batches, sometimes manually. Batch operations are typical of older, smaller municipal incinerators many of which have been shutdown (see following sections). About 150 to 200 percent excess air is supplied to the incinerator [compared with the 30 to 50 percent excess air typical of industrial coal-fired boilers (92)]. The large volumes of combustible exhaust gases generated are sometimes burned in secondary chambers (multichamber units). The exhaust gases, which contain POM resulting from the incomplete combustion of organic material in the waste, exit through stacks to the atmosphere. Large units operating continuously at high temperatures achieve more efficient combustion than smaller units and thus produce less POM per mass of waste material combusted (90).

The average MSW incinerator can process about 16,000 kg/hr [385 metric tons/day (424 tons/day)] of solid waste (90). At most large facilities, the waste is burned as received with an effort made only to separate out very large non-combustible items.

Boilers fired with MSW also burn the waste as received, with only minor separation. Typical new MSW boilers can process about 181-2720 metric tons/day (200 to 3000 tons/day) of refuse (133). Heat input capacities of existing units range from 1.3 to 85 MW (4.5 x 10^6 to 290 x 10^6 Btu/hr) (93). [85 MW is approximately equal to 545 metric tons/day of waste burned for these units.]

Industrial Waste Combustion--Industrial wastes combusted in incinerators consist primarily of processing wastes and plant refuse and contain paper, plastic, rubber, textiles, and wood. Because of the variety of manufacturing operations, waste compositions are highly variable between plants, but may be fairly consistent within a plant. Also, existing industrial boilers are used to burn refuse-derived fuel (RDF), either alone or with coal.

In addition, a recenty published paper (89) reports that as much as 18 million metric tons (20 million tons) of hazardous wastes are burned annually in existing industrial boilers.

Industrial incinerators are basically the same design as municipal incinerators. Available data (based on a sample of over 300 units) indicate that 91 percent of the units were multichamber designs, 8 percent were single chamber designs, and 1 percent were rotary kiln or fluidized bed designs (94). About 1500 of the estimated 3800 industrial incinerators are used for volume reduction, 640 units (largely in the petroleum and chemical industries) are used for toxicity reduction, and the remaining 1700 units are used for resource recovery, primarily at copper wire and electric motor plants. Some industrial boilers are specifically designed to fire waste fuels. There are about 50 of these units, ranging up to about 7.6 MW (26 x 10^6 Btu/hr) heat input capacity (93).

Refuse-derived fuel is a solid waste fuel that has been processed or classified to remove non-combustible materials. RDF can be co-fired with coal in existing boilers or in boilers designed specifically for RDF. There are an estimated six facilities either operational or under construction that will fire only RDF (93).

Apparently some existing coal- and oil-fired industrial boilers are being used to burn hazardous wastes (89). Characteristics of these boilers were discussed in Section 5.3.

Commercial Waste Combustion--Incinerators are used to reduce the volume of wastes from medical facilities, large office complexes, schools, and commercial facilities. Small multichamber incinerators are typically used and over 90 percent of the units require firing of an auxillary fuel. Because of the inefficient combustion in these units, they can be a potentially significant source of POM (95). Operating skills of commercial and industrial incinerator operators are usually limited.

5.8.1.2 Emission Controls/Regulations

This section presents a summary of the emission controls typically used on existing waste combustion sources and general information on the air emission regulations applicable to these sources.

No quantitative data on the effect of emission controls on POM emissions were located, but the general principles described in Section 5.3 apply here:

- particulate matter control technologies designed to collect fine particles (ESPs, fabric filters) will be effective in controlling POM compounds which preferentially condense on smaller particles, and

- wet scrubbers can be effective in reducing POM emissions that are in the vapor phase, because those compounds are condensed as the gas is cooled in the scrubber.

Highlights of the emission regulations applicable to existing and new waste combustion sources are discussed below.

Municipal Waste Combustion--MSW incinerators and boilers firing MSW with a capacity of 45 metric ton/day (50 tons/day) or greater and constructed after August 1971 are subject to an NSPS (96) that requires about 93 percent control of particulate emissions (97). Boilers and incinerators burning municipal wastes are also subject to SIP emission and opacity limits in most states. These are sometimes regulated together under the designation of "fuel-burning equipment" (98).

New MSW-fired boilers will also be regulated under the industrial boiler NSPS currently being developed by EPA. The proposed standard will likely require the use of ESPs.

Industrial Waste Combustion--Industrial incinerators are subject to SIP particulate and opacity standards in all 50 states. The typical standard requires that outlet particulate emissions be controlled to about 0.45 gr/Nm^3 (0.2 gr/dscf) at 12 percent CO_2 (99), or slightly greater than 80 percent control (100). Opacity limits generally range between 10 and 30 percent (99). Most industrial incinerators are currently equipped with after-burners, but new units may be required to have scrubbers or ESPs (101).

New industrial boilers firing waste or RDF will be subject to the NSPS being developed by EPA, which will likely require the use of scrubbers or ESPs. Existing industrial boilers are subject to SIP emission limits depending on location, size, and fuel type. As discussed in Section 5.3.1.2, emission controls used on existing sources vary from relatively inefficient mechanical collectors to high efficiency ESPS and fabric filters. At least 40 percent of the existing RDF and RDF/coal capacity is controlled with ESPs (102).

Commercial Waste Combustion--No specific information was located for these sources, but they may be subject to SIP particulate and/or opacity levels. However, they are unlikely to be equipped with efficient emission controls. Reference 95 reports that most "commercial" incinerators are equipped with afterburners, but includes industrial incinerators in their definition.

5.8.1.3 Source Locations

Municipal Waste Combustion--MSW incineration without heat recovery has been declining in recent years due to the inability of older units to comply with applicable air emission regulations. As of 1979-1980, there were slightly more than 100 operating MSW incinerators spread over 19 states, most located in the eastern and middle portions of the country (103). The highest concentrations of these sources were in New York City and Chicago.

Most of the MSW-fired boilers are also located near urban population centers (104).

Industrial Waste Combustion--No specific location data were available for industrial incinerators or waste-fired boilers. However, the locations of these units will obviously parallel those of the industries that rely on them. The lumber and wood products, primary metal, and printing industries are expected to be the major users of large incinerators. The lumber and wood products industry is located primarily in the Southeast and Northwest. Primary metals are concentrated in the Appalachian and Great Lakes regions.

Commercial Waste Combustion--Concentration of these units will follow urban population patterns.

5.8.2 Emission Factors

Emission factors for total POM from waste combustion were available only for MSW incinerators and commercial incinerators, and even these data were quite limited. Most of the available data were originally reported in a 1967 study (105). No information was provided on the composition of the waste fired during the tests, a major factor influencing POM emissions.

Table 5-21 shows available PAH emission data for four MSW incinerators and a commercial incinerator. The PAH compounds reported are indicated in the footnotes. Two previously described trends are supported by these data:

- Uncontrolled emission factors were highest for the commercial incinerator, followed by the smaller MSW unit. The larger MSW unit had the lowest uncontrolled emission factor. These data, although very limited, tend to support the trend of less POM per unit of refuse burned for larger, more efficient incinerators.
- The scrubber and scrubber/ESP combination both showed significant reduction of PAH relative to uncontrolled.

Emissions of polychlorinated biphenyl compounds (a subset of POM not included in PAH) have been reported to be between 0.10 to 0.16 gm/metric ton of municipal solid waste incinerated (based on two studies) (106).

5.8.3 National Emission Estimates

Development of national POM estimates was possible only for MSW incinerators and commercial and industrial incinerators. Due to a lack of data regarding the amounts of waste combusted, emissions were developed by multiplying the average unit capacity by the estimated number of units, an average annual capacity factor, and an emission factor.

The average MSW incinerator capacity has been reported to be 385 metric tons/day (424 tons/day) and there are an estimated 104 units nationwide (95). A 70 percent average annual capacity factor was assumed in lieu of specific

TABLE 5-21. PAH EMISSION FACTORS FOR MSW AND COMMERICAL INCINERATORS

Source Type (Reference)	Capacity (metric ton/day)	Emission Control	PAH Emissions (gm/metric ton incinerated)
Small, Batch MSW Incinerator-reciprocating grate (106)	45	None	0.310[a]
		Water-Spray	0.016[a]
Large, Continuous Multichamber Incinerator-traveling grate (106)	225	None	0.042[a]
Large, Continuous Incinerator-rocking bar grate (106)	216	Wet scrubber/ESP	0.014[b]
Commercial Incinerator (geometric mean of two types of units - one a single chamber, the other a multichamber with auxillary gas firing) (107)	2.7 to 4.8	None	6.8[c]

[a] Compounds measured in sample: Benzo(a)pyrene, pyrene, benzo(e)pyrene, coronene, benzo(g,h,i)perylene, fluoranthene, phenanthrene. Perylene, anthracene, anthanthracene were analyzed for but not detected.

[b] Also includes benz(a)anthracene, chrysene, benzofluoranthenes, perylene, and indeno(1,2,3c,d)pyrene.

[c] No information on POM compounds included in emission factor.

data for MSW incinerators. This assumption was based on a reported average commercial incinerator capacity utilization of 71 percent (95). The PAH emission factor presented in Section 5.8.2 for large MSW incinerators controlled with the scrubber/ESP system was selected as representative of the current population. The size of the unit tested was similar to the average size MSW incinerator. The emission factor reported for PCB was not included because of the relatively small size of the incinerator tested (0.11 metric tons/day). Thus, the PAH emission factor may result in a low estimate of total POM. National PAH estimates for MSW incinerators were calculated as:

$$\left(\frac{365\ \text{days}}{\text{yr}}\right)\left(\frac{385\ \text{metric tons incinerated}}{\text{day-unit}}\right)\left(0.7\ \text{capacity factor}\right)\left(104\ \text{units}\right)\times$$

$$\left(\frac{0.014\ \text{gm PAH}}{\text{metric ton}}\right)\left(\frac{\text{metric ton}}{10^6\ \text{gm}}\right)$$

$$= 0.14\ \text{metric tons/yr}\ (0.16\ \text{tons/yr})$$

A similar method was used to calculate PAH emissions from commercial and industrial incinerators:

$$\left(\frac{365\ \text{days}}{\text{yr}}\right)\left(0.71\ \text{capacity factor}\right)\left(\frac{2.5\ \text{metric tons}}{\text{unit day}}\right)\left(100{,}000\ \text{units}\right)\left(\frac{6.8\ \text{gm PAH}}{\text{metric ton}}\right)\times$$

$$\left(\frac{\text{metric ton}}{10^6\ \text{gm}}\right) = 440\ \text{metric tons/yr.}\ (485\ \text{tons/yr})$$

Average capacity, capacity utilization, and the number of units were obtained from Reference 95. Industrial incinerators were included with commercial incinerators in the available data on capacity and number of units. In lieu of other data being available, the emission factor for commercial units was assumed to apply to industrial incinerators.

It should be emphasized that these emission estimates are highly uncertain. They are based on a very limited data; they may not reflect total POM emissions (i.e., polychlorinated biphenyls); and they do not reflect the actual composition and amounts of waste combusted. Also, no data were available to develop accurate POM emission estimates for MSW-fired boilers, industrial incinerators or industrial boilers burning solid waste, hazardous wastes, or RDF. Of these sources, industrial incinerators may potentially be the most significant because of their relatively lower combustion efficiencies and lack of controls.

5.8.4 Trends Influencing POM Emissions

Municipal Waste Combustion--The trend is toward larger, more efficient MSW incinerators due to air emission regulations (90). These larger units will generally be equipped with ESPs. One reference reports that the trend in emission control selection for MSW incinerators has been forced away from scrubbers because of the failure of some earlier poorly designed impingement scrubbers (108).

Reported growth projections for MSW incineration are that about 5 new units will be built by 1985, each at about 2270 metric tons/day (2,400 tons/day) capacity. Six large MSW-fired boilers are expected to be built by 1990 (93). These new units will likely be controlled with ESPs or wet scrubbers.

Industrial Waste Combustion--Industrial incineration is expected to decline, especially for use in volume reduction purposes (109). This trend is reportedly due to land disposal techniques becoming more economical as a result of more stringent air emission regulations (109). Exceptions to the decline in industrial incinerators include (109):

- incineration with heat recovery (especially in the lumber, pulp, and paper, and other industries with combustible wastes), and
- resource recovery from copper wire and electric motor incineration.

One study has suggested that the complications of RCRA rules and the associated recordkeeping requirements may lead to increased (and unregulated) combustion of hazardous wastes in existing boilers (89). This could be a significant source of POM emissions depending on the types of waste incinerated, existing emission controls, and regulatory development related to RCRA.

Six new RDF-fired units with a total heat input capacity of about 380 MW are expected to be build by 1990 (93). The co-firing of RDF in existing coal-fired boilers may increase due to general incentives to reduce fuel-related costs.

Commercial Waste Combustion--No significant changes in capacity or types of wastes incinerated are expected in this category.

5.9 CARBON BLACK PRODUCTION

5.9.1 Source Category Description

5.9.1.1 Process Description

Carbon black is produced by pyrolysis of an atomized liquid hydrocarbon mixture. One of its main uses is as a reinforcing agent in rubber tires. About 90 percent of U.S. carbon black is produced by the oil-furnace process. Temperatures in the refractory-lined steel furnaces vary between 1320 and 1540°C. The heat for the decomposition reaction is supplied by combustion of natural gas. The pyrolysis reaction is a source of POM emissions (110).

Hot furnace gas, containing carbon black particles, is cooled to about 230°C and then passed through a fabric filter for recovery of the carbon black (110). Exhaust gas from the fabric filter is vented to the atmosphere or sent to an emission control device. The main process vent is the major source of POM emissions in a carbon black plant. Emissions may depend to some degree on the type of carbon black produced due to required differences in furnace operation as a function of product specifications.

5.9.1.2 Emission Controls/Regulations

About two-thirds of U.S. carbon black plants use a combustion device (flare, CO boiler, or thermal incinerator) on the main process vent (110). No quantitative data were available on the effect of these systems on POM emissions. Although the use of a combustion device might be expected to reduce POM emissions, "high temperatures" (in the combustion devices) could reportedly lead to formation of additional POM (110). No temperatures were specified in the reference reviewed.

However, in addition to the combustion control device, most carbon black furnaces are equipped with fabric filters for product recovery. Thus, POM condensed on the captured carbon black particles will be removed from the exhaust gas stream.

Existing carbon black plants are generally subject to SIP particulate emission limits. New plants would be covered by prevention of significant deterioration (PSD) requirements, but no NSPS exists for this source category.

5.9.1.3 Source Locations

Carbon black plants are located in Louisiana, California, West Virginia, Arkansas, Oklahoma, and New Jersey (111). As of 1977, about 60 percent of the U.S. production capacity was located in Louisiana.

5.9.2 Emission Factors

Total uncontrolled POM emissions from an oil-furnace carbon black plant were measured in a previous study using a modified Method 5 sampling train (110). Samples were extracted, separated by liquid chromatography, and analyzed by GC/MS. A total POM emission factor of 1.9 gm/metric ton (3.8×10^{-3} lb/ton) of carbon black produced was reported. Acenaphthylene accounted for about 46 percent by weight of the POM in the samples collected. Table 5-22 lists the POM compounds detected in the collected samples.

5.9.3 National Emission Estimates

Reference 110 puts the U.S. carbon black production capacity at 1.72×10^6 metric tons (1.9×10^6 tons/yr). In 1980, the value of carbon black shipments was $540 million (112). At about $0.50/bulk kg of carbon black (113), this translates into approximately 1.08×10^6 metric tons/yr (1.19×10^6 tons/yr), or 57 percent of capacity. Thus, national POM emisisons from carbon black production can be estimated as:

$$\left(\frac{1.08 \times 10^6 \text{ metric tons carbon black}}{\text{yr}}\right)\left(\frac{1.9 \text{ gm POM}}{\text{metric ton produced}}\right)\left(\frac{\text{metric ton}}{10^6 \text{ gm}}\right)$$

$$= 2.05 \text{ metric tons/yr } (2.26 \text{ tons/yr})$$

This estimate may be somewhat high since it is based on an uncontrolled POM emission factor (110) and, as stated above, about two-thirds of the plants currently have combustion devices for emission control. However, no data were available to quantify the effect of such combustion-type controls on POM emissions.

5.9.4 Trends Influencing POM Emissions

A two to three percent annual growth rate has been projected for the carbon black industry (114). Some of this growth appears possible without construction of new facilities as indicated by the 57 percent capacity utilization figure presented above. New plants will likely be subject to PSD permitting requirements that require some form of emission control.

TABLE 5-22. POM COMPOUNDS IN SAMPLES FROM OIL-FURNACE CARBON BLACK PLANT (110)

Acenaphthylene (46% of total)
Anthracene/phenanthrene
Benzofluoranthenes
Benzo(g,h,i)fluoranthene
Benzo(g,h,i)perylene/anthanthrene
Dibenzanthiocenes
Dibenzo(c,g)carbazole
Dibenzopyrenes
Dibenzothiophene
Dimethylanthracenes/phenanthrenes[a]
7,12 Dimethylbenz(a)anthracene
Fluoranthene
Indeno(1,2,3-c,d)pyrene
Methylanthracenes/phenanthrenes[a]
Methylcholanthrene
Methylfluoranthene/pyrene
Pyrene (26% of total)

[a] Together these groups accounted for 12% of total.

5.10 WOOD CHARCOAL PRODUCTION

5.10.1 Source Category Description

5.10.1.1 Process Description*

Charcoal, primarily used for outdoor cooking, is manufactured by the pyrolysis of carbonaceous raw materials. The raw materials used are primarily medium to dense hardwoods. Softwoods, sawmill residue, nutshells, fruit pits and vegetable wastes can also be used. (This study was limited to examining charcoal production from wood.) There are two major types of techniques used in wood charcoal manufacture:

- Missouri-type batch kiln, and
- Continuous Herreshoff furnace.

The batch process accounts for about 45 percent of the national production (a small portion of this capacity is accounted for by older beehive kilns). Continuous furnaces, which generally have a much larger capacity than batch kilns, account for the remainder for production capacity. The kiln or furnace products are sold directly or made into briquettes.

A Missouri-type batch kiln normally processes about 45 to 50 cords of wood in a 10- to 25-day cycle. Kiln temperatures are in the 450 to 510°C range and pyrolysis of the wood products is a source of POM emissions. Missouri-type kilns have exhaust stacks along the side walls. The required burn time and resulting emissions from the batch kiln vary with kiln capacity, operational practices, wood species, and wood moisture content.

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*The information presented in this subsection is summarized from References 115 and 116.

Continuous charcoal production is accomplished in Herreshoff multiple hearth furnaces. Furnace temperatures range between 480° and 650°C. The off-gases exit through the stacks located on top of the furnace or are used as a heat source (e.g. predrying of feed, drying of briquettes produced at an adjacent location, or combustion in a waste heat boiler to produce steam.) Use of continuous Herreshoff furnaces requires a large and steady source of raw materials. The typical continuous furnace capacity is 2.5 metric tons/hr (2.75 tons/hr).

5.10.1.2 Emission Controls/Regulations

Emission control of batch kilns is complicated by the cyclic nature of the process. Direct-fired afterburners are probably the most feasible control system, but auxiliary fuel use is required with these devices. If fuels other than natural gas are used as the auxiliary fuel there is a potential for additional POM emissions. No data were located on the percentage of batch kilns equipped with afterburners. No data were located on the effect of afterburners on POM. Natural gas would likely have to be used as the auxiliary fuel to avoid additional POM emissions.

Many of the batch kilns are older and relatively small batch kilns are likely to be uncontrolled (115,116).

Continuous furnaces can also be controlled by direct-fired afterburners. Auxilliary fuel firing is required only during start-up or process upsets on continuous units because of the higher heating value of the exhaust gases. An incinerator is used to control emissions in at least one continuous furnace plant, but afterburners are reportedly used on most continuous furnaces (117).

There is no NSPS for charcoal manufacturing, although the feasibility of developing a standard was investigated (115). Charcoal manufacturing facilities are generally subject to SIP particulate emission limits and opacity regulations. Some plants may be subject to CO standards.

5.10.1.3 Source Locations

Charcoal manufacturing facilities are located primarily in Missouri, Arkansas, and other Southeastern states (118). Missouri accounts for a large share of the national production, although about 24 states have a wood charcoal industry.

5.10.2 Emission Factors

POM emission factor data were available only for a Missouri-type batch kiln (119). An average of five sampling runs showed total POM uncontrolled emissions of 0.35 gm/hr (770 x 10^{-6} lb/hr). Based on limited production data provided in Reference 119, this translates into about 3.5 gm/metric ton of charcoal produced (0.007 lb/ton). The authors report that the samples, collected with a modified Method 5 apparatus and analyzed by gas chromatograph, contained benz(c)phenanthrene, benzo(a)pyrene, and "POM-like" material. Four POM compounds were analyzed for, but not detected: dibenz(a,h)anthracene, 3-dimethylcholanthrene, 7,12 dimethylbenz(a)anthracene, and 3,4,5,6-dibenzocarbazole.

It should be noted that the emission tests were considered of questionable value due to the difficulty of sampling the kiln and "the improvisational sampling techniques" used. No estimate of the accuracy was provided. Also, no emission data were reported for the initial ignition process during which gas can escape from the kiln.

5.10.3 National Emission Estimates

The estimated 1978 charcoal production capacity was 376,340 metric tons (414,000 tons) distributed as follows (120).

Process	Production	% Total
Missouri-type batch kiln	198,180	52.7
Beehive kiln	2,730	0.73
Continuing Herreshoff furnace	175,460	46.6
	376,370	

Charcoal production in 1980 was assumed to be about the same since there has been no indication of growth in the industry (121).

Based on these data, national POM emissions from Missouri-type kilns were calculated as:

$$\left(\frac{198{,}180\text{ metric tons charcoal}}{\text{yr}}\right)\left(\frac{3.5\text{ gm POM}}{\text{metric ton}}\right)\left(\frac{\text{metric ton}}{10^6\text{ gm}}\right)$$

$$= 0.69\text{ metric ton/yr } (0.76\text{ ton/yr})$$

Although an emission factor was not available for continuous furnace production, is is expected that POM emissions will be substantially less (on a mass per mass of charcoal produced basis) than for batch kilns. This is because of the capability of the continuous furnace to use non-direct fired afterburners or incinerators or to recover the heating value of the exhaust gases through other combustion devices. These techniques should reduce POM emissions. Thus, at a maximum, total POM emissions from this category should be:

$$\left(\frac{198{,}180 + 175{,}460\text{ metric tons charcoal}}{\text{yr}}\right)\left(\frac{3.5\text{ gm POM}}{\text{metric ton}}\right)\left(\frac{\text{metric ton}}{10^6\text{ gm}}\right)$$

$$= 1.3\text{ metric tons/yr } (1.4\text{ tons/yr})$$

This is a "worst-case" estimate since it is based on the higher emission factor of the Missouri-kiln.

5.10.4 Trends Influencing POM Emissions

There is a general trend in the industry toward fewer but larger plants that are more amenable to emission control than many of the existing small plants. In addition, small plants have been forced to close in some states (Florida, Illinois, Ohio, and Oklahoma) because of problems in complying with state emission regulations (121). Also, the level of charcoal production has remained relatively stable in recent years. There are no indications of future growth in the industry, as briquettes are increasingly being manufactured from other materials such as lignite. Thus, POM emissions from this category are not expected to increase in the future.

5.11 VEHICLE DISPOSAL

5.11.1 Source Category Description

5.11.1.1 Process Description

Three types of techniques are used to remove the organic material from auto bodies before they are used as scrap by the steel industry (usually in electric arc furnaces). The organic material can be removed by (122):

- open burning of whole auto bodies
- incineration of whole auto bodies, or
- shredding of auto bodies and incineration of the shredded steel.

Incineration of shredded steel is generally accomplished in rotary kilns. The combustion efficiency of the kilns is relatively high, reducing the potential for POM emissions (122). Open burning has a considerably higher potential for POM emissions than incineration because of the low combustion efficiency typical of open burning.

5.11.1.2 Emission Controls/Regulations

Open burning is generally prohibited especially in most metropolitan areas, but may still occur either illegally or outside restricted areas.

Incineration of whole auto bodies would likely be subject to SIP particulate matter emission limits applicable to incinerators. Mechanical collectors, wet scrubbers, and ESPs are candidate control technologies for incinerators. No specific information was located with regard to the application of controls to incineration of auto bodies.

5.11.1.3 Source Locations

No source location data were readily available. However, incineration of auto bodies would be expected to coincide with steel industry locations.

5.11.2 Emission Factor Data

No POM emission factors for vehicle disposal were located.

5.11.3 National Emission Estimates

No emission factor or consumption data were located.

5.11.4 Trends Influencing POM Emissions

The demand for auto scrap by the steel industry is increasing due to an increase in the use of electric arc furnaces. These furnaces can accomodate a high proportion of scrap in the furnace feed (122). Concurrently, the increase in demand has made shredding and subsequent incineration of auto body steel in rotary kilns more economically attractive (122). The trend toward this higher combustion efficiency technique, combined with continued enforcement of open burning prohibitions, may result in steady or decreased POM emissions even, as the demand for auto body scrap is increased.

5.12 MOBILE SOURCES

This section discusses the following mobile source categories with potential for POM emissions:

- gasoline-fueled autos and trucks,
- diesel autos and trucks, and
- rubber tire wear.

5.12.1 Source Category Description

5.12.1.1 Process Descriptions

Gasoline Autos and Trucks--Emissions of POM from combustion of gasoline in autos and light-duty trucks are dependent on several factors, including (123):

- inefficient combustion because of less than stoichiometric air to fuel ratios,
- driver operation techniques that lower fuel efficiency,
- engine deterioration and combustion chamber deposits,
- aromatic content of the gasoline and presence of lead additives.

The pyrolysis of motor oil deposits built up on the engine may also be a potential source of POM emissions (123).

Diesel Autos and Trucks--The primary causes of POM emissions from diesel combustion in autos and trucks are overloading and poor engine maintenance (124). However, even under normal operating conditions, diesel autos tend to emit more POM than their gasoline-fueled counterparts. The higher emissions of POM may be due to the relatively lower combustion-chamber temperatures typical of diesel engines (124). Diesel autos emit 30 to 100 times more particulate matter per mile than gasoline autos equipped with catalytic converters. Diesel particulates are usually less than 1 μm in diameter and consist of a carbonaceous core. Many different soluble organic compounds are absorbed on these particles, some of which are POM (125).

Rubber Tire Wear--Carbon black and other tire materials possibly containing POM are released to the atmosphere through oxidation and normal wear of rubber tires (124).

5.12.1.2 Emission Controls/Regulations

Gasoline Autos and Trucks--The control devices used on recent model autos have the capability to reduce POM emissions. Exhaust gas recirculation, which was introduced in 1968, has been reported to reduce PAH emissions by 65 to 80 percent over uncontrolled (123). Catalytic converters, which generally are used on post-1975 models, have been reported to reduce PAH emissions by up to 99 percent (123).

Federal and state mobile source emission regulations generally require the use of unleaded gasoline and catalytic converters for recent year models. The regulations also limit emissions of NO_x, CO, and hydrocarbons (HC) and evaporative losses. Some states have implemented regular inspection and maintenance (I/M) programs for autos.

Diesel Autos and Trucks--Exhaust controls are not commonly used on diesel-fueled vehicles. However, proper loading, fueling, and maintenance of diesel engines can reduce their POM emissions (124).

Federal and California state regulations limit HC, NO_x, CO, and evaporative losses from diesel autos and light duty trucks. States have the option of implementing either the Federal or California standards, but are restricted from implementing more stringent standards for diesel-fired vehicles (126).

Rubber Tire Wear--Emission controls or regulations are not applicable to this source.

5.12.1.3 Source Locations

Source locations data is not applicable to mobile sources, although their concentrations are obviously higher in urban areas.

5.12.2 Emission Factors

Reference 131 provided emission factors for several PAH compounds emitted from gasoline and diesel vehicles (Table 5-23). These values were based on measured emission data and "derived emission factors." The emission factors were then multiplied by estimated 1979 fuel consumption data for the various types of mobile sources to develop the total estimates presented in the next section. The PAH compounds included are listed in Table 5-24.

The authors note that the derived emission factors are quite uncertain and may vary by a factor of two or more. The two major assumptions used in developing the emission factors in Table 5-23 were (131):

- that the "PAH distributions" for both gasoline and diesel vehicles are the same as the distribution for average light-duty gasoline vehicles not equipped with catalytic converters, and
- that all PAH emissions are reduced by catalytic converters as much as BaP emissions are reduced by such devices.

5.12.3 National Emission Estimates

Table 5-25 shows the 1979 estimated PAH emissions from several mobile source categories including gasoline and diesel autos and trucks, buses,

TABLE 5-23. PAH EMISSION FACTORS FOR GASOLINE AND DIESEL VEHICLES (131)

Vehicle Type	Fuel Type	PAH Emission Factor[a] μg/gal	 μg/mi[b]
Light-duty, no catalytic converter	Leaded Gasoline	45242	3235
Light-duty, oxidation catalyst	Unleaded Gasoline	7457	418
Light-duty, three-way catalyst	Unleaded Gasoline	881	45
Heavy-duty, no catalytic converter	Leaded Gasoline	45242	9052
Light-duty	Diesel Fuel	48269	1925
Heavy-duty	Diesel Fuel	48269	8048

[a] Table 5-24 lists the POM compounds included.

[b] μg/mi = (μg/gal) ÷ (mi/gal)

TABLE 5-24. POM COMPOUNDS INCLUDED IN DERIVED MOBILE SOURCE EMISSION FACTORS (131)

Anthracene
Phenanthrene
Methylphenanthrene
Dimethylfluorene
Dimethylphenanthrene
Fluoranthene
Pyrene
Benzofluorene
Benzoanthracene
Triphenylene
Cyclopentapyrene
Chrysene
Indenofluoranthene
Idenopyrene
Methylchrysene
1-Nitropyrene
Benzofluoranthene
Benzo(e)pyrene
Benzo(a)pyrene
Perylene
Cyclopentabenzopyrene
Benzochrysene
Anthanthrene
Dibenzanthracene
Benzoperylene
Coronene
Cyclopentabenzoperylene

TABLE 5-25. NATIONAL 1979 PAH EMISSIONS FROM MOBILE SOURCES[a,b] (131) (metric tons)

Anthracene	350
Phenanthrene	1,400
Methylphenanthrene	900
Dimethylfluorene	470
Dimethylphenanthrene	320
Fluoranthene	750
Pyrene	950
Benzofluorene	120
Benzoanthracene	37
Triphenylene	30
Cyclopentapyrene	390
Chrysene	150
Indenofluoranthene	19
Indenopyrene	30
Methylchrysene	6
1-Nitropyrene	17
Benzofluoranthene	110
Benzo(e)pyrene	52
Benzo(a)pyrene	43
Perylene	4
Cyclopentabenzopyrene	26
Benzochrysene	1
Anthanthrene	22
Dibenzanthracene	13
Benzoperylene	110
Coronene	80
Cyclopentabenzoperylene	18
	6,400

[a] Total for all PAHs: about (3)(6,400) = about 19,000 metric tons.

[b] Includes autos, trucks, motorcycles, railroads, aircraft, ships, and farm and military mobile sources.

motorcycles, railroads, ships, aircraft, and farm and military mobile sources. The emission factors for heavy-duty gasoline and diesel vehicles were used to estimate emissions for the categories other than gasoline and diesel autos and trucks.

The largest portion of PAH emissions from the various mobile source categories is attributable to older gasoline autos not equipped with catalytic converters (131). However, emissions from this category are expected to decrease as these older vehicles are taken out of service.

5.12.4 Trends Influencing POM Emissions

Gasoline Autos and Trucks--Consumption of gasoline in autos and trucks is expected to decrease in future years due primarily to the use of more fuel-efficient vehicles, conservation of fuel induced by increasing prices, and the increased use of diesel autos. Between 1978 and 1982, gasoline demand dropped by slightly less than 12 percent (128). Combined with continued emission control requirements and I/M programs, the trend of decreasing gasoline consumption may result in decreased POM emissions from this category.

Diesel Autos and Trucks--A wide range of estimates exist regarding the projected increase of diesel fuel in autos. However, it is likely that at least 20 percent of light duty vehicles will be diesel-fueled by 1995 (129). Total distillate fuel demand is projected to increase at least 2 percent between 1982 and 1983, with the majority of the increase attributed to diesel fuel consumption in autos and trucks (128).

This trend could result in increased POM emissions from diesel-fueled vehicles if emission control technologies continue not to be used. Potential control techniques for diesel engines include turbocharging and modification of the combustion chamber and fuel injection system (130). These modifications should improve combustion efficiencies and in turn reduce the POM emitted per unit of fuel consumed.

Rubber Tire Wear--No significant changes are foreseen in POM emissions from rubber tire wear other than increases associated with total miles traveled by the vehicle-operating population.

5.13 REFERENCES

1. Energy and Environmental Analysis, Inc. Preliminary Assessment of the Sources, Control and Population Exposure to Airborne Polycyclic Organic Matter (POM) as Indicated by Benzo (A) Pyrene (BaP). Final Report, Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, p. 95, November 10, 1978.

2. Chalekode, P.K. and T.R. Blackwood. Source Assessment: Coal Refuse Piles, Abandoned Mines, and Outcrops - State of the Art. EPA-600/2-78-004v, U.S. Environmental Protection Agency, Cincinnati, OH, July 1978.

3. Reference 2, p. 2-11.

4. Formica, Peter N. (TRC). Controlled and Uncontrolled Emission Rates and Applicable Limitations for 80 Processes. EPA-340/1-78-004, U.S. Environmental Protection Agency, Research Triangle Park, NC, pp. II-1 to II-2, April 1978.

5. Reference 1, p. 99-100.

6. Reference 2, Section 5.

7. Evans, John S. and Douglas W. Cooper. "An Inventory of Particulate Emissions from Open Sources," Journal of the Air Pollution Control Association, 30(12), pp. 1298-1303, December 1980.

8. Reference 1, p. 98-99.

9. Shih, Chris, et al. (TRW, Inc.). POM Emissions from Stationary Conventional Combustion Processes. CCEA Issue Paper, U.S. Environmental Protection Agency, Research Triangle Park, NC, p. 15, January 1980.

10. Reference 9, p. 3.

11. Reference 1, pp. 43-44.

12. Baig, S., et al (TRW) and Hurley, T. et al. (Radian Corporation) Conventional Combustion Environmental Assessment Final Report. EPA Contract No. 68-02-3138, U.S. Environmental Protection Agency, Research Triangle Park, NC, p. 4-8, July 1981.

13. Reference 1, p. 22.

14. U.S. Department of Energy. Electric Power Annual. DOE/EIA-0348(81), Washington D.C., p. 13, November 1982.

15. U.S. Department of Energy. State Energy Data Report: 1960 through 1980. DOE/EIA-0214(80), Washington, DC, p. 9, July 1982.

16. Emission Standards and Engineering Division. (U.S. Environmental Protection Agency.) Fossil Fuel-Fired Industrial Boilers-Background Information Volume 1: Chapters 1-9. EPA-450/3-82-006a, p. 3-2, March 1982.

17. Reference 15, p. 7. Total adjusted to reflect only the fuel consumed by boilers. Adjustment factors (1974 data) were obtained from: Energy and Environmental Analysis, Inc. Fossil Fuel-Fired Industrial Boilers - Background Information for Proposed Standards, Appendices F and G. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, NC, p.F-12, March 9, 1981. Adjustment factors (% of total energy consumption used in boilers): Coal-30%; Oil-67%; and Gas-40%.

18. Reference 15, p 6. All consumption reported assumed to be in boilers and furnaces.

19. Reference 1, p. 55.

20. Reference 1, p. 51.

21. Reference 5, p. 5.

22. Reference 12, p. 5-57, 5-52.

23. Laseke, B.A., M.T. Melia, and N.G. Bruck. (Ped Co. Environmental Inc.) "Trends in Commercial Application of FGD Technology." Presented at the EPA/EPRI Seventh Symposium on Flue Gas Desulfurization, Hollywood, Florida, May 17-20, 1982, p. 2-1. The % capacity figures shown in the table are based on 275,000 MW installed coal-fired capacity as reported in: U.S. Department of Energy. Inventory of Power Plants in the United States - 1981 Annual. DOE/EIA-0095(81), Washington DC, p. 19, September 1982. (Assumes all FGD capacity reported applied to coal units since no other data were readily available).

24. Kelly, M.E. and M.A. Palazollo. Status of Dry SO_2 Control Systems--Fall 1982. Final Report, EPA Contract No. 68-02-3171, Task 58, U.S. Environmental Protection Agency, Research Triangle Park, NC, p. 19, January 1982.

25. Reference 2, p. 5-58.

26. Code of Federal Regulations. 40 CFR 60, Part 30, Subparts D and Da, pp. 234-261, Revised July 1, 1982.

27. Reference 16, pp. 4-66 to 4-81.

28. Reference 24, p. 23.

29. Reference 16, Chapter 3.

30. Reference 16, p. 4-16.

31. Reference 16, p. 4-39.

32. Foster, Kathye L., et al. "Permitting a Wood-Burning Boiler in a Major Metropolitan Area," Journal of the Air Pollution Control Assoc. 32(8), pp. 872-877, August, 1982.

33. Jones, Larry (EPA-OAQPS). Personal communication with M.E. Kelly, Radian Corporation, regarding regulatory status of commercial/institutional boilers. April 21, 1983.

34. U.S. Department of Energy. Inventory of Power Plants in the United States-1981 Annual. DOE/EIA-0095(81), Washington, D.C., September 1982.

35. Bergman, Michael K. and Robert M. Dykes. (U.S. Environmental Protection Agency). Prospects for Increasing the Direct Use of Coal in Industrial Boilers. Draft Report, Research Triangle Park, NC, p. 68-80.

36. DeAngelis, D.G. et al. (Monsanto Research Corporation). Source Assessment: Residential Combustion of Wood. EPA-600/2-80-024b, U.S. Environmental Protection Agency, Research Triangle Park, NC, p. 21, March 1980.

37. Energy Information Administration (U.S. Department of Energy). Estimates of U.S. Wood Energy Consumption from 1949 to 1981, DOE/EIA-0341, August 1982.

38. Piper, B.F., S. Hersh, and W. Nazimowitz (KVB, Inc). Combustion Demonstration of SRC II Fuel Oil in a Tangentially Fired Boiler. EPRI Final Report, FP-1029, Palo Alto, California, pp. 7-22 to 7-23, May 1979.

39. Wainwright, Phyliss B. et al. (NC Dept. of Natural Resources). A POM Emissions Study for Industrial Wood-Fired Boilers. Department of Natural Resources, Raleigh, NC, April 1982.

40. Radian Corporation. Background Information Document for Non-Fossil Fuel-Fired Boilers. Draft Report (EPA-450/3-82-007), EPA Contract No. 68-02-3058, U.S. Environmental Protection Agency, Research Triangle Park, NC, Chapter 3 and p. 6-18, March 1982.

41. Eimutis, E.C. and R.P. Quill (Monsanto Research Corporation). Source Assessment: Non-Criteria Pollutant Emissions. EPA-600/2-77-107e, p. 78, July 1977.

42. Peters, J.A. and D.G. DeAngelis (Monsanto Research Corporation). High Altitude Testing of Residential Wood-Fired Combustion Equipment. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, NC, September, 1981.

43. Reference 16, pp. 4-58 to 4-60.

44. Reference 35, Chapter 1.

45. Reference 40, p. 3-6.

46. Emission Standards and Engineering Division (U.S. Environmental Protection Agency). Coke Oven Emissions from By-Product Coke Oven Charging, Door Leaks, and Topside Leaks on Wet Coal-Charged Batteries--Background Information for Proposed Standards. Draft Report, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 1981.

47. Suta, Benjamin E. (SRI International). Human Population Exposure to Coke Oven Atmospheric Emissions. EPA Contract No. 68-02-2835, Final Report, U.S. Environmental Protection Agency, Research Triangle Park, NC, Revised May 1979.

48. Reference 1, p. 68.

49. Reference 46, pp. 3-60, 3-61.

50. Reference 46, pp. 3-54, 3-62.

51. Reference 46, p.7-7.

52. Emission Standards and Engineering Division (U.S. Environmental Protection Agency). *Coke Wet Quenching--Background Information for Proposed Standards*. Draft Report, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 25, 1982.

53. Reference 46, pp. 3-1, 3-2.

54. Reference 52, p. 3-38.

55. Laube, A.H. and B.A. Drummond (York Research Corporation). *Coke Quench Tower Emission Testing Program*. EPA-600/2-79-082, U.S. Environmental Protection Agency, Research Triangle Park, NC, p. 7, April 1979.

56. Berry, Kent (U.S. Environmental Protection Agency). Personal communication with Mary Kelly, Radian Corporation, March 3, 1983 (through Ray Morrison, U.S. Environmental Protection Agency).

57. Reference 46, p. 3-2.

58. Reference 46, p. 3-18.

59. Reference 1, p. 26.

60. Reference 46, pp. 3-41, 3-42.

61. Reference 55, p. 3-4.

62. Reference 1, p. 78-79.

63. Emission Standards and Engineering Division (U.S. Environmental Protection Agency). A Review of Standards of Performance for New Stationary Sources - Ferroalloy Production Facilities. EPA-450/3-80-041, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1980.

64. Pahl, Dale (EPA-OAQPS). Personal communications with Mary E. Kelly, Radian Corporation, regarding regulatory status of various iron and steel source categories, April 13 and April 21, 1983.

65. Reference 63, p. 25-29.

66. Reference 63, pp. 47-50.

67. Industrial Environmental Research Laboratory (U.S. EPA). Level 1 Environmental Assessment of Electric Submerged-Arc Furnaces Producing Ferroalloys. EPA-600/2-81-038, pp. 6-7, 15, March 1981.

68. Industry and Trade Administration (U.S. Department of Commerce). 1980 U.S. Industrial Outlook for 200 Industries with Projections for 1984. U.S. Department of Commerce, Washington, DC, Chapter 16, January 1980.

69. Kahn, Z.S. and T.W. Hughes. (Monsanto Research Corporation) Source Assessment: Asphalt Hot Mix. EPA-600/2-77-107n, U.S. Environmental Protection Agency, Cincinnati, OH, p. 93, December 1977.

70. Gerstle, R.W. (PedCo Environmental, Inc.) Atmoshperic Emissions from Asphalt Roofing Processes. EPA-600/2-74-101, U.S. Environmental Protection Agency, Washington, DC, Chapter 4, October 1974.

71. Reference 69, p 8.

72. Reference 69, pp 34-36.

73. Reference 70, pp 19-20.

74. Reference 1, p 73.

75. NSPS for asphalt hot mix. 40CFR60, Subpart I. NSPS for asphalt roofing products: 40CFR60, Subpart UU.

76. Reference 69, pp. 50-52.

77. Reference 70, p. 2 and pp. 43-45.

78. Energy Information Administration (U.S. Department of Energy). DOE Energy Data Reports: "Sales of Asphalt in 1980". DOE/EIA-0112(80), U.S. Department of Energy, Washington, DC, June 8, 1981.

79. Reference 1, pp. 72-78.

80. Reference 69, p. 7.

81. Reference 68, p. 7.

82. Reference 1, pp. 60-62.

83. Reference 26, Subpart J.

84. Pacific Environmental Services, Inc. Inspection Manual for Enforcement of New Source Performance Standards: Catalytic Cracking Regenerators. EPA-340/1-77-006, U.S. Environmental Protection Agency, Washington, DC, pp. 2-1, 2-2, April 1977.

85. Reference 1, pp 25-26.

86. Oil and Gas Journal. Refinery Forecast Issue. March 30, 1981.

87. Oil and Gas Journal. Forecast Review Issue. pp 132-133. January 2, 1982.

88. Reference 84, pp. 3-3.

89. Coyle, J.J. and E. J. Potenta (Fred C. Hart Associates, Inc.). "Population Exposure to Hazardous Air Pollutants from Waste Combustion in Industrial Boilers and RCRA Regulated Incinerators". Presented at the APCA Specialty Conference on Measurement and Monitoring of Non-Criteria (Toxic) Contaminants in Air, Chicago, IL, March 1983.

90. Reference 1, pp. 85-87.

91. McIlvaine Company. U.S. Incinerator Air Pollution Control Equipment Market. McIlvaine Company, Northbrook, IL, p. 3, October 1981.

92. Reference 16, p. 6-17.

93. Reference 40, pp. 3-6 to 3-9.

94. Reference 91, p. 8.

95. Reference 1, pp. 87-89.

96. Reference 26, Subpart E.

97. Reference 91, p. 21.

98. Reference 40, p. 3-59.

99. Reference 91, pp. 18-19.

100. Estimated from MSW incinerator control level and corresponding efficiency (Reference 97).

101. Reference 91, pp. 39-41.

102. Reference 40, p. 4-2.

103. Reference 1, Appendix F and p. 86.

104. Reference 40, p. 3-6.

105. Hangebrauck, R.P., D.J. vonLehmden, and J.E. Meeker. Sources of Polynuclear Hydrocarbons in the Atmosphere. AP-33, NTIS PB 174-706. U.S. Public Health Service, Washington, DC, 1967.

106. Shih, C. et al. (TRW, Inc.) POM Emissions from Stationary Combustion Sources with Emphasis on Polychlorinated Compounds of Dibenzo-p-Dioxin, Biphenyls, and Dibenzofuran. CCEA Issue Paper, EPA Contract No. 68-02-3138, U.S. Environmental Protection Agency, Research Triangle Park, NC, pp 17-21, January 1980.

107. Reference 1, p. 28.

108. Reference 91, p. 37.

109. Reference 91, pp. 52-53.

110. Serth, R.W. and T.W. Hughes. "Polycyclic Organic Matter (POM) and Trace Elements Contents of Carbon Black Vent Gas", Environmental Science and Technology, 14(3), pp. 298-300, March 1980.

111. Reference 1, Appendix E.

112. Reference 68, p. 112.

113. Chemical Marketing Reporter. December 1, 1980.

114. Reference 1, p. 81.

115. Hulman, P.B. et al (Radian Corporation). Screening Study on Feasibility of Standards of Performance for Wood Charcoal Manufacturing, Final Report, EPA Contract No. 68-02-2608, Task 32. Prepared for U.S. Environmental Protection Agency, Research Triangle Park, NC, August 1978.

116. Moscowitz, C.W. (Monsanto Research Corporation). Source Assessment: Charcoal Manufacturing - State-of-the-Art. EPA-600/2-78-004z, U.S. Environmental Protection Agency, Cincinnati, OH, December, 1978.

117. Reference 115, p. 42.

118. Reference 116, pp. 19-20.

119. Maxwell, W.H. (Midwest Research Institute). Stationary Source Testing of a Missouri-Type Charcoal Kiln NTIS PB-258695, U.S. Environmental Protection Agency, Kansas City, MO, pp 10-17, August 3, 1976. (Average of runs 2, 4, 6, 8, and 10).

120. Reference 115, p. 20.

121. Reference 115, pp. 21-22.

122. Reference 1, p. 96-97.

123. Reference 1, p. 103-107.

124. Reference 1, p. 108-113.

125. Klausmeier, Rob (Radian Corporation). A Study of the Impact of Light Duty Vehicle Growth on Colorado's Air Quality, Draft Report, Prepared for Colorado Department of Health, Radian Corporation, Austin, Texas, pp. 2-5, November 3, 1981.

126. Reference 125, p. 6-17.

127. Reference 1, p. 30.

128. Buck, Robert, "Demand, Imports to Rise in '83; Production to Slip." Oil and Gas Journal 81(4), pp. 71-103, January 31, 1983.

129. Reference 125, p. vi.

130. Reference 125, p. iii.

131. National Research Council. Polycyclic Aromatic Hydrocarbons: Evaluation of Sources and Effects. National Academy Press. Washington, D.C., Chapter 1, 1983.

132. U.S. Environmental Protection Agency, Supplement 12 for Compilation of Air Pollutant Emission Factors, AP-42. NTIS PB 82-101213. Research Triangle Park, NC, pp. 8.1-3 to 8.1-5, April 1981.

133. Meyer, Ron (U.S. Environmental Protection Agency). Personal communication with Ray Morrison, EPA Project Officer, August 29, 1983.

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APPENDIX A

ADDITIONAL CALCULATIONS FOR ESTIMATING POM EMISSIONS FROM COMBUSTION SOURCES

APPENDIX A

Additional Calculations for Estimating POM Emissions from Combustion Sources

Section

A.1 Conversion of Reported Emission Factors to consistent units

A.2 Wood consumption in industrial boilers

A.3 Wood consumption in residential stoves

A.1 Conversion of Reported Emission Factors

(Common unit basis [=] lb POM/10^{12} Btu heat input)

A.1.1 Coal Combustion

Emission factors were provided in terms of μg or mg per kg of coal burned (1). Assume a coal heating value of 11,500 Btu/lb, which is representative of several bituminous and subbituminous coals (2,3).

$$\text{Utility boilers: } \left(\frac{19\text{x}10^{-6}\text{gm POM}}{\text{kg coal}}\right)\left(\frac{\text{lb coal}}{11{,}500\text{ Btu}}\right)\left(\frac{0.454\text{ kg}}{\text{lb}}\right)\left(\frac{\text{lb}}{454\text{ gm}}\right)$$

$$= 1.65\text{ lb}/10^{12}\text{ Btu}$$

Industrial boilers: $\left(\frac{41\text{x}10^{-6}\text{gm POM}}{\text{kg coal}}\right)\left(\frac{\text{lb coal}}{11{,}500\text{ Btu}}\right)\left(\frac{0.454\text{ kg}}{\text{lb}}\right)\left(\frac{\text{lb}}{454\text{ gm}}\right)$

$= 3.57\text{ lb}/10^{12}\text{Btu}$

Residential: $\left(\frac{67\text{x}10^{-3}\text{gm POM}}{\text{kg coal}}\right)\left(\frac{\text{lb coal}}{11{,}500\text{ Btu}}\right)\left(\frac{.454\text{ kg}}{\text{lb}}\right)\left(\frac{\text{lb}}{454\text{ gm}}\right)$

$= 5826\text{ lb}/10^{12}\text{Btu}$

A.1.2 Oil Combustion

Emission factors were provided in terms of μg POM per liter of oil burned (1). Assume an oil heating value (#6 Resid) of about 150,000 Btu/gal (4).

Utility: [already in terms of lb/Btu--(5)] $= 2.0\text{ lb}/10^{12}\text{Btu}$

Industrial: $\left(\frac{21\text{x}10^{-6}\text{gm POM}}{\text{liter oil}}\right)\left(\frac{\text{liter}}{0.2642\text{ gal}}\right)\left(\frac{\text{gal}}{150{,}000\text{ Btu}}\right)\left(\frac{\text{lb}}{454\text{ gm}}\right)$

$= 1.17\text{ lb}/10^{12}\text{Btu}$

Residential: $\left(\frac{120\text{x}10^{-6}\text{gm POM}}{\text{liter oil}}\right)\left(\frac{\text{liter}}{0.2642\text{ gal}}\right)\left(\frac{\text{gal}}{150{,}000\text{ Btu}}\right)\left(\frac{\text{lb}}{454\text{ gm}}\right)$

$= 6.67\text{ lb}/10^{12}\text{Btu}$

A.1.3 Natural Gas Combustion

Emission factors were provided in terms of μg or mg per m^3 of gas burned (1). Assume a natural gas heating value of 35,300 Btu/m^3 [1000 Btu/ft^3] (6).

Industrial: $\left(\frac{11\text{x}10^{-6}\text{gm POM}}{\text{m}^3\text{ gas}}\right)\left(\frac{\text{m}^3}{35{,}300\text{ Btu}}\right)\left(\frac{\text{lb}}{454\text{ gm}}\right)$

$= 0.69\text{ lb}/10^{12}\text{Btu}$

Residential: $\left(\frac{65\text{x}10^{-6}\text{gm POM}}{\text{m}^3\text{gas}}\right)\left(\frac{\text{m}^3}{35{,}300\text{ Btu}}\right)\left(\frac{\text{lb}}{454\text{ gm}}\right)$

$= 4.06\text{ lb}/10^{12}\text{Btu}$

A.1.4 Wood Combustion

Emission factors provided in terms of μg or mg per kg of dry wood burned (7). Assume a (dry) wood heating value of 8600 Btu/lb (8).

Industrial: $\left(\frac{2.1\text{x}10^{-3}\text{gm POM}}{\text{kg wood}}\right)\left(\frac{0.454\text{ kg}}{\text{lb}}\right)\left(\frac{\text{lb}}{8600\text{ Btu}}\right)\left(\frac{\text{lb}}{454\text{ gm}}\right)$

$= 237\text{ lb}/10^{12}\text{Btu}$

Residential Stoves: $\left(\frac{0.27\text{ gm POM}}{\text{kg wood}}\right)\left(\frac{0.454\text{ kg}}{\text{lb}}\right)\left(\frac{\text{lb}}{8600\text{ Btu}}\right)\left(\frac{\text{lb}}{454\text{ gm}}\right)$

$= 31{,}400\text{ lb}/10^{12}\text{Btu}$

Residential Fireplaces: $\left(\frac{0.029\text{ gm POM}}{\text{kg wood}}\right)\left(\frac{.454\text{ kg}}{\text{lb}}\right)\left(\frac{\text{lb}}{8600\text{ Btu}}\right)\left(\frac{\text{lb}}{454\text{ gm}}\right)$

$= 3370\text{ lb}/10^{12}\text{Btu}$

A.2 Wood Consumption in Industrial Boilers

Reference 9 reports 1600 wood-fired industrial boilers with a total capacity of 1.04×10^{11} Btu/hr in operation in 1978. At an average capacity factor of 60% (10), this translates into an annual wood consumption of

$$\left(\frac{1.04 \times 10^{11} \text{Btu}}{\text{hr}}\right)\left(\frac{8760 \text{ hr}}{\text{yr}}\right)(0.60) = 547 \times 10^{12} \text{Btu}.$$

This was the most recent consumption data for wood-fired boilers, and no trend data (specific to boilers) were available to allow extrapolation to 1980. Therefore, 1978 consumption figures were used to estimate national POM emissions from this category.

A.3 Wood Consumption in Residential Stoves and Fireplaces

Reference 8 puts annual wood use in stoves at 26 million metric tons (dry basis). Using the estimated 8600 Btu/lb dry wood heating value (8) yields:

$$(26 \times 10^{12} \text{gm}) \left(\frac{\text{lb}}{454 \text{ gm}}\right)\left(\frac{8600 \text{ Btu}}{\text{lb}}\right) = 492 \times 10^{12} \text{Btu}.$$

Reference 8 reports 1980 wood consumption in fireplaces as 17.3 million metric tons:

$$(17.3 \times 10^{12} \text{gm})\left(\frac{\text{lb}}{454 \text{ gm}}\right)\left(\frac{8600 \text{ Btu}}{\text{lb}}\right) = 328 \times 10^{12} \text{Btu}.$$

A.4 References

1. Energy and Environmental Analysis, Inc. Preliminary Assessment of the Sources, Control, and Population Exposure to Airborne Polycyclic Organic Matter (POM) as Indicated by Benzo(a)pyrene. Final Report, prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, Table III-1 (intermediate factors for POM), November 10, 1978.

2. Emission Standards and Engineering Division (U.S. Environmental Protection Agency). Fossil Fuel-Fired Industrial Boilers-Background Information Volume 1: Chapters 1-9. EPA-450/3-82-006a, Chapter 3, March 1982.

3. Babcock and Wilcox. Steam: Its Generation and Use. 39th edition, Babcock and Wilcox, New York, Chapter 5, 1978.

4. Reference 2, Table 6-5. Divide heat input rate to boiler by fuel rate to calculate Btu/gal oil.

5. Piper, B.F., S. Hersh, and W. Nazimowitz (KVB, Inc.). Combustion Demonstration of SRC II Fuel Oil in a Tangentially Fired Boiler. EPRI Final Report, FP-1029, Palo Alto, California, pp. 7-22 to 7-23, May 1979.

6. Reference 2, Table 6-5. Divide heat input rate by fuel rate to calculate Btu/m^3 of gas.

7. Industrial: Wainwright, Phyliss B. et al. (NC Dept. of Natural Resources). A POM Emission Study for Industrial Wood-Fired Boilers. Department of Natural Resources, Raleigh, NC, April 1982.

Residential: DeAngelis, D.G. et al. (Monsanto Research Corporation). Source Assessment: Residential Combustion of Wood. EPA-600/2-80-024b, U.S. Environmental Protection Agency, Research Triangle Park, NC, p. 21, March 1980.

8. Energy Information Administration (U.S. Department of Energy). Estimates of U.S. Wood Energy Consumption from 1949 to 1981. DOE/EIA-0341, August 1982.

9. Radian Corporation. Background Information Document for Non-Fossil Fuel-Fired Boilers. Draft Report (EPA-450/3-82-007), EPA Contract No. 68-02-3058, U.S. Environmental Protection Agency, Research Triangle Park, NC, p. 3-3, March 1982.

10. Reference 9, model wood-fired boiler in Chapter 6.